Proximity to Food Outlets and Diabetes-Related Health Outcomes: A Cross-Sectional Study in Robeson County, NC

By
Madhulika Vulimiri

Honors Thesis
Department of Health Policy and Management
University of North Carolina at Chapel Hill

April 2014

Approved:

(Student's Advisor)

Introduction

Type 2 diabetes is a growing epidemic in the United States, and already affects 25.8 million Americans (8.3%) in 2011.[1] The prevalence of type 2 diabetes has nearly tripled from 1990 to 2010 and is projected to increase.[2] If this pattern continues, the Centers for Disease Control and Prevention (CDC) estimates that one-third of Americans will have type 2 diabetes by 2050.[3] In North Carolina, this problem is particularly acute; the state has the 13th highest prevalence of diabetes at 9.8% of the general population.[4] Robeson County—a rural area with a large American Indian population of Lumbee descent—has shown dramatically higher diabetes prevalence than the rest of the state, at 13.7%.[5] The high prevalence of diabetes in Robeson County raises significant concerns about the long-term health status its residents.

Research has shown that lifestyle modifications, including dietary changes, can reduce the development of diabetes, as well as the need for treatment of existing diabetes.[6] Unfortunately, rural areas tend to have a dearth of healthy food retailers, such as supermarkets, while boasting a plethora of fast food options.[7] Due to various barriers—such as distance to, and price of, healthy food options—low-income and minority groups living in rural areas are even less likely to have consistent access to healthy, affordable food.[8,9,10] Without a healthy diet, it can be challenging for individuals to achieve optimal control over diabetes risk factors, such as A1c level, blood pressure level, and body mass index (BMI).[11] Over time, poor eating behaviors can heighten one's risk for developing diabetes, or experiencing diabetes-related complications such as kidney failure, amputation, or blindness.[12] It is important to evaluate access to healthy food options in Robeson County to inform future intervention and policy action to reverse diabetes trends in this area.

While many individuals living in rural areas lack access to healthy food options and are subsequently at risk for developing diabetes, low-income and minority groups face even higher risk for diabetes morbidity and mortality.[13] Minority groups are disproportionately represented among the poor, and low socioeconomic status is often associated with limited access to affordable, healthy food.[14] Robeson County, with nearly 30% of individuals in poverty,[15] and nearly 40% of individuals of American Indian descent,[16] has many residents that are particularly vulnerable to the risk factors that cause diabetes. At present, little is known about the specific interaction between geographic access to healthy foods and diabetes in a predominantly rural, low-income, and minority area, such as Robeson County.

Researchers have begun using Geographic Information Systems (GIS) mapping technology to explore the food environment, as it offers the benefit of visually determining ‘food activity spaces,’ the geographic locations and variety of food outlets at which individuals shop.[17] The impetus for using GIS in Robeson County came from the CEO of Robeson Health Care Corporation (RHCC), a federally qualified health center with four clinics serving patients in Robeson County. This research aims to use GIS to better understand the relationship between food access and various diabetes-related risk factors in Robeson County, North Carolina in order to ultimately inform community policy changes.

Research Questions

- *How is geographic distance to food outlets associated with uncontrolled diabetes (represented by A1c > 9%, SBP > 140 mmHg, and BMI > 30)?*
- *How far does the sample of patients live from food outlets in Robeson County?*
- *How many food outlets are in Robeson County?*
- *Is there a bivariate correlation between BMI and A1c, BMI and SBP, and A1c and SBP?*

Hypotheses

I hypothesize the following:

- The distance from patients' home (proximity) to the closest chain supermarket will be positively associated with A1c level such that greater distance will be associated with a higher A1c level, higher BP, and higher BMI.
- The proximity from the patients' home to the closest fast-food restaurants will be inversely associated with A1c level such that greater distance will be associated with a lower A1c level, lower BP, and lower BMI.

Literature Review

Diabetes among vulnerable groups

Type 2 diabetes is a metabolic disease characterized by abnormally high levels of blood glucose, which result from a defect in insulin production, insulin action, or both.[18,19] Many factors can increase one's risk for type 2 diabetes, including race/ethnicity, old age, obesity, family history of diabetes, poor diet, and physical inactivity.[20] Type 2 diabetes is a major cause of morbidity and mortality in the United States. Not only is it a key risk factor for heart disease and stroke,[21] but, left uncontrolled, type 2 diabetes can result in severe health complications, such as kidney failure, blindness, and amputation of limbs.[22] It is also the seventh leading cause of death, with a national age-adjusted mortality rate of roughly 21.5 deaths per 100,000 individuals in 2011.[23]

In addition to posing significant health risks, diabetes is a costly disease, both to individuals and to society at large. The American Diabetes Association estimates that the total cost of diagnosed diabetes (type 1 or 2) was $245 billion in 2012, which breaks down to $176 billion in direct medical costs and $69 billion in reduced productivity.[24] A 2013 study found that the average lifetime cost of type 2 diabetes was $85,200, of which roughly half were attributed to treating diabetes-related complications.[25] The growing prevalence of type 2 diabetes thus poses a significant health policy concern in the United States.

Currently, type 2 diabetes affects 25.8 million Americans, which is roughly 8.3% of the population.[26] The Centers for Disease Control and Prevention have identified a "diabetes belt," in which at least 11% of the population has been diagnosed with diabetes.[27] People who live in the diabetes belt, which spans 15 states (including North Carolina), are more likely to have type 2 diabetes than people who live in other parts of the country. [28] The burden of this disease, in both North Carolina and the United States, falls disproportionately on minority and low-income populations.[29] In 2010, the national age-adjusted diabetes prevalence was 16.1 per 1,000 American Indians/Alaskan Natives, 12.6 per 1,000 in African Americans, 11.8 per 1,000 Hispanics/Latinos, and 7.1 per 1,000 Non-Hispanic Whites.[30] These populations may face barriers to controlling diabetes as a result of cultural and socioeconomic factors, language barriers, and poorer access to consistent, quality care.[31]

In Robeson County, North Carolina, diabetes prevalence has gradually increased each year from 2002 (7.9%), the first year in which data was collected, to 2010 (13.7%), the most recent data available.[32] The prevalence of diabetes in Robeson County is currently higher than both the North Carolina and national average.[33] In 2011, diabetes was the fourth leading cause of death in Robeson County.[34] The age-adjusted death rate from diabetes in Robeson County, at 54.5 per 100,000, is more than double the average rate for North Carolina, 23.6 per 100,000.[35] Moreover, the burden of the disease falls largely along racial and socioeconomic lines. As seen in Table 1, black females face the highest risk for diabetes-related mortality; other minority females, such as American Indian and Hispanic women, come in second highest for diabetes death rate.[36]

Table 1. 2005-2009 Robeson County race-specific and sex-specific age-adjusted death rates. Source: Robeson County 2011 Community Health Assessment.

	White		African American		Other		Robeson	NC
	Male	Female	Male	Female	Male	Female	Overall	Overall
Diabetes mellitus death rate*	47.7	33.4	56.9	80.6	56.8	68.2	**54.5**	**23.6**

*Death rates per 100,000 population.

Robeson County has a unique racial/ethnic composition as a majority-minority county that is home to the Lumbee American Indian tribe.[37] American Indians, of Lumbee descent, comprise the largest racial/ethnic group (39.0%), followed by Non-Hispanic Whites (32.8%), African Americans (24.7%), Hispanic/Latinos (8.2%), and Asians (0.8%), with an overall population of 135,496 in 2012.[38] Roughly 30% of Robeson County residents live in poverty, making Robeson one of the poorest counties in North Carolina.[39] This distinctive mix of socioeconomic factors makes Robeson County a key area to understand the factors influencing diabetes prevention and treatment.

Food access in minority, low-income, and rural areas

The public health and medical communities have long established that maintaining a healthy diet, participating in regular physical activity, not smoking, and adhering to prescribed medicine regimens are key behaviors for chronic disease management, especially with diabetes.[40] Healthy eating is especially vital to regulating blood sugar levels and properly managing diabetes.

Diabetes patients commonly undergo an A1c test to gauge how well they are managing their diabetes. The A1c test is a blood test that reflects a patient's average blood glucose level for the past two to three months.[41,42] The test measures the percentage of one's hemoglobin—a protein in red blood cells that carries oxygen—that is coated with sugar.[43] A higher A1c level indicates poorer blood glucose control and higher risk for diabetes-related complications.[44] A normal A1c level for an individual without diabetes ranges from 4.5% to 6%.[45]

Historically, healthcare providers have focused on controlling diabetes by reducing patients' A1c levels to 7% or less.[46] Recent research suggests, however, that "intensive glucose control," or reducing A1c levels to less than 6.5%, may not benefit middle-aged patients with type 2 diabetes, and may actually result in adverse cardiovascular events, such as heart attacks.[47,48] Nevertheless, ensuring that A1c is roughly near 7% is still an important goal of diabetes control. A1c control is important—every percentage point reduction in mean A1c correlates with a 37% reduction in risk of microvascular complications (e.g. diabetic nephropathy, neuropathy, and retinopathy) and a 21% reduction in risk of diabetes-related end point and deaths.[49]

Additionally, providers monitor blood pressure levels and BMI, which are both significant risk factors for developing type 2 diabetes as well as developing diabetes-related morbidities. Blood pressure control is particularly important, as risk of ischemic heart disease and stroke increases progressively and linearly starting at blood pressure levels as low as 115/75 mmHg.[50]

In order to maintain a healthy A1c level, blood pressure level, and body weight, the American Diabetes Association has long recommended that individuals with diabetes should consume low-fat, high-fiber foods, such as fruits, vegetables, and whole grains in order.[51] Recent investigations might alter this conventional recommendation, and suggest that diabetics should consume "healthy" fats (e.g. olive oil, nuts), as found in a Mediterranean diet, rather than adhere to the traditional low-fat diet.[52] While more research needs to be done to determine whether or not to expand the definition of a "healthy diet," there is consensus that a diabetes diet should include a variety of nutritious foods in moderate amounts and sticking to regular mealtimes.[53]

It can be particularly challenging to maintain a healthy diet in the modern food environment in the United States. The well-established presence of processed and convenient food in many settings, like schools, workplaces, and stores, presents one challenge.[54] Families are also increasingly eating meals away from home.[55] Finally, there has been an exodus of supermarkets from and influx of fast-food restaurants into low-income areas.[56] Keeping up with a diabetes-friendly diet can be even more difficult for individuals who live in low-income, minority, or rural communities with limited access to healthy food.[57]

Many parts of the United States are still deeply divided by socioeconomic status. Residential segregation by race and income often has significant consequences for where food outlets decide to locate their businesses.[58] Minority and low-income areas are more likely to be "food deserts," which are defined as "areas without ready access to fresh, healthy, and affordable food."[59] Food deserts can refer to a literal absence of food sold in a defined area, but can also refer to differences in "accessibility to healthy and affordable food between socioeconomically advantaged and disadvantaged areas."[60] A 2009 systematic review of food deserts found clear evidence that predominantly low-income or African American residential areas were less likely to be served by food retailers compared to more affluent, predominantly white areas.[61] Another study found that half of all black neighborhoods in the United States lack full-service grocery stores and supermarkets, which are thought to have the best variety of produce and healthy food at low cost.[62,63] Often, these regions tend to also have many fast food restaurants and convenience stores that sell energy-dense or "empty calorie" foods in excess.[64] Recently, Rose et al. who studied urban food access in New Orleans termed these areas "food swamps," or "areas in which large relative amounts of energy-dense snack foods inundate healthy food options."[65]

Disparities in food access are exacerbated in rural areas, which tend to have limited, more expensive food outlets[66] (including more convenience stores[67] and fewer supermarkets[68]) compared to urban or suburban areas. Sharkey (2009) notes that rural food environments are more likely to have convenience stores (with or without gas stations), non-traditional food stores (such as drug stores with food), and sometimes, conventional stores (such as supermarkets and grocery stores).[69] Some rural areas have few or no supermarkets for many miles.[70] A systematic review of 54 studies between 1985 and 2008 found that people who live in rural, low-income, or minority communities are less likely to have access to supermarkets, chain grocery stores, or healthy food products.[71] A national study representing 28,000 zip codes found that there were 14% fewer chain supermarkets in rural and farm areas, as compared to urban areas.[72] Healthy foods are likely to be in short supply in rural areas; this may influence the food choices of minority and low-income individuals with diabetes.[73]

It is clear that geography, among other factors, can determine one's access to healthy, affordable food. In the last decade, researchers have begun to use geographic analysis (through the use of GIS mapping and other tools) to visualize the local food environment. A systematic review of articles measuring the community-level food environment found that most studies defined "food access" by looking at (1) "diversity," the density and type of food outlets within a specific area, (2) "proximity," the nearest distance to food outlets, or (3) "variety," the overall availability of different types of food outlets, as well as their price and quality.[74] Another way to examine "diversity" is to look at "coverage," or counts, of food venues in buffers of different sizes.[75] A study by Jilcott et al. (2011) examined the association between various measures of food venue accessibility and BMI percentile, using measures of proximity and coverage.[76] In 2013, Jilcott et al. used GIS to explore the relationship between access to farmers' markets and supermarkets and health indicators among low-income women in North Carolina.[77] They measured access by examining proximity, but specifically looking at (1) the distance to the closest food outlet to the residential location, and (2) the mean distance travelled to the food outlets where women reported shopping. There is growing evidence that food access is associated with race/ethnicity, socioeconomic status, and location, but there is limited research about how geographic food access impacts diabetes health outcomes.

Relevance for Robeson County

Robeson County is a primarily rural county, with a small urban center (Lumberton) as its county seat, and a large public university close to the urban center (University of North Carolina-Pembroke). Lumberton is classified as "urban" by the Census, because it has a population density greater than 1,000 people per square mile;[78,79] in comparison, the population density of Robeson County is 141.3 persons per square mile.[80]

Given that Robeson County has a unique racial/ethnic composition and rural classification, it is a key area for the study of food access in the context of diabetes management. According to the Community Commons map, 21.9% (N = 29,468 out of

134,168 residents) of Robeson County's residents live in food deserts, defined as "low-income census tracts where at least 33% of the tract's population lives more than 10 miles away from a supermarket or large grocery store."[81] County Health Rankings show that 55% of all restaurants in Robeson County are fast food establishments.[82] Moreover, the percentage of adults in Robeson County who consume the recommended 5 or more servings of fruits and vegetables per day is less than that of North Carolina (16.2% vs. 20.6%).[83] While cultural practices and food preferences may influence healthy eating behaviors, a thorough understanding of food access is also important to diabetes prevention and control in Robeson County.

Methods

Research design

This study used a cross-sectional design, which examines a specific population over a short period of time by measuring the exposure prevalence in relation to the disease prevalence.[84] Through a secondary data analysis, the study used GIS mapping capabilities in the open-source R Statistical Programming Language to analyze existing patient data collected from 2010 to 2011.[85] GIS tools provide researchers the ability to map community-level variables to show spatial relationships between health predictors and outcomes.[86] When combined with quantitative analysis, GIS tools can lead to the development, implementation, monitoring, and evaluation of community interventions that can positively influence public health.[87]

Data collection

This study used patient data from 2010-2011 that was abstracted from electronic medical records by the Robeson Health Care Corporation (RHCC). This dataset includes patients' most recent A1c level, SBP level, and BMI. In the dataset, patients' A1c levels are categorized as "strict control" (under 7), "control" (7 to 8), "borderline control" (8 to 9), and "uncontrolled" (over 9).

Previously geocoded and anonymized patient addresses were imported into the open-source R Statistical Programming Language, along with the associated patient data (i.e. A1c, BP, and BMI). Due to limited time to explore the entire food environment in Robeson County, this research study focused specifically on access to supermarkets, fast food restaurants, convenience stores, and farmers' markets. Food outlet addresses were obtained from two sources: (1) the ReferenceUSA® business database (www.referenceusa.com) and (2) ascertaining uncertain addresses by ground-truthing, the process of verifying a satellite image with what is already known about the location on the ground.[88] Because commercial data is not always accurate, all addresses were verified through telephone calls to confirm that businesses were currently operating, and web searches and Google Maps Streetview function to confirm their existence.

The addresses of all food outlets were converted to GPS coordinates and verified using Texas A&M Geocoding Services. Food venues were separated into the following categories: supermarkets (including grocery stores), fast food restaurants, convenience stores, and farmers' markets (including produce stands). ReferenceUSA was used to classify food outlets according to the following North American Industry Classification System (NAICS) codes: 72221101/3/4/5 = fast-food restaurants, 44511001/2/3/4/5 = supermarkets and grocery stores, and 452910 = supercenters and discount clubs.[89]

The addresses were converted to GPS coordinates, verified, and imported into R software. This study quantified patients' access to food outlets by calculating the 'proximity' or distance to the closest food outlet, following a similar methodology outlined by Rose et al.[90] and performed by Jilcott, et al.[91] The R software will calculate the Euclidean distance (straight line, from point A to point B) to closest food outlets using the *sp* package.[92,93,94] Distances were divided into cutpoints of 1 mile for convenience stores and 2 miles for fast food restaurants and supermarkets because these reflected the mean distances to food outlets. Previous studies of food access have also used the 1-mile and 2-mile measures of proximity based on the expectation that food outlets could be reached by motor vehicle in a short period of time.[95,96]

Definition of food outlets

In this analysis, "fast food restaurants" includes chain fast food restaurants as well as local drive through restaurants. "Supermarkets" include both chain supermarkets and small grocery stores, which generally have a wide selection of food.[97] "Convenience stores" include those that are attached to gas stations, those that standalone, food marts, and Hispanic *tiendas*. Convenience stores typically sell a limited selection of goods such as milk, bread, soda, and snacks.[98] It is important to note that, while the majority of convenience stores only sell nonperishable foods, some do additionally offer hot food, such as hamburgers, hot dogs, and wings, prepared on a grill. "Farmers' markets" include both farmers' markets and roadside produce stands.

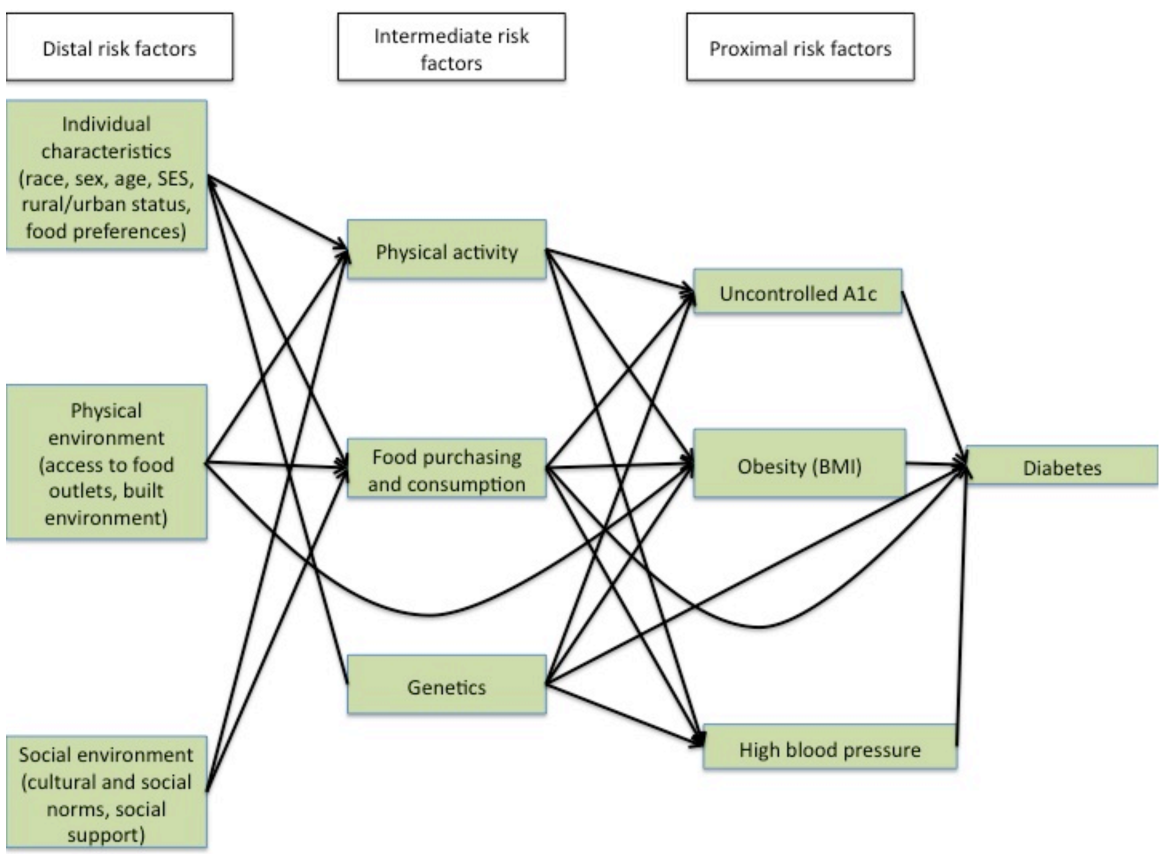
Participants and sampling methods

This research study focused specifically on patients who receive healthcare services from Robeson Health Care Corporation (RHCC) in Robeson County. RHCC is a private, non-profit federally qualified health center that provides primary and preventative healthcare services to patients in the counties of Robeson, Columbus, Scotland, Montgomery, Moore, Johnston, and Pitt. The sample was limited to patients who met two criteria: (1) they have had at least once visit to any of the four clinical sites belonging to RHCC in Robeson County (in the towns of Pembroke, Lumberton, Maxton, and Fairmont), and (2) they received a type 2 diabetes diagnosis code sometime between 2010 and 2011 (N = 1,780). Because type 2, or "adult onset," diabetes is the outcome of interest, this study excludes patients who are pre-diabetic or who have type 1 diabetes. There were 1,297 non-unique observations of patients in the dataset, meaning that there were some patients in the dataset who had multiple A1c measures. This could be because the cohort represents a sample of diabetes patients who may have attended RHCC multiple times between 2010 and 2011.

Conceptual model

In order to consider the potential confounders of distance to food outlets and A1c level, I drew upon Directed Acyclic Graphs (DAGs) and conceptual models from existing literature.[99,100,101,102] DAGs are used to visually represent causal relationships between exposures, outcomes, and covariates and to identify potential confounders.[103,104] Based on the associations found between covariates in the literature, I created the conceptual model seen in Figure 1.

Fig. 1. Conceptual model documenting proximal, intermediate, and distal risk factors for diabetes.



Based on this conceptual model, I adjusted the logistic regression models to account for additional covariates that are proximal, intermediate, or distal risk factors for diabetes. This analysis measures the relationship between one aspect of the physical environment (i.e. distance to food outlets) and various diabetes risk factors (i.e. A1c, BMI, and SBP), seen in the first and third column of Figure 1. This analysis does not adjust for the covariates that are intermediate risk factors in the second column, because that information is not available.

Fig. 2. Stepwise logistic regression model-building process.

Model 1: Unadjusted [distance to closest fast food restaurant]

Model 2: Food outlet type [distance to closest convenience store + distance to closest farmers' market]

Model 3: Model 2 + [BMI + SBP]

Model 4: Model 3 + [race + sex + rural status]

Models were run in a stepwise process in order to see whether associations remained after adding covariates. The first model run observed the relationship between distance to fast food restaurants and A1c, and was unadjusted for any covariates. The second model adjusted for distance to closest convenience stores and distance to closest farmers' markets as independent variables to reflect the fact that one's local food environment is composed of a variety of food outlets and restaurants. Model 3 adjusted for additional diabetes risk factors, such as BMI and SBP. Finally, model 4 adjusted for individual characteristics, like race (specifically American Indian race), sex (specifically male gender), and rural location. The logistic regression models were adjusted, or controlled, for these covariates because there is evidence that obese body mass index (BMI),[105] high SBP,[106] and uncontrolled A1c,[107] as well as American Indian race,[108] rural location,[109] and male gender[110] are associated with increased prevalence of type 2 diabetes.

It is important to note that the logistic regression with BMI as an outcome did not control for A1c or SBP because BMI is typically a predictor for A1c and SBP, and not vice versa.

Data analysis methods

Pearson's correlation coefficients were calculated to test associations between BMI and SBP, A1c and SBP, and BMI and A1c (see Table 2A in appendix).

Multiple logistic regression analysis was used to test whether distance to various food outlets were associated with several diabetes risk factors (i.e. A1c level, BMI, and SBP) among diabetic patients in Robeson County, after controlling for covariates (such as rural location, American Indian race, and male gender).[111] [112] Multiple logistic regression extends simple regression to allow for more than one regressor.[113] In multiple regression, the regression coefficients are called partial slopes, and they can only be interpreted in the context of the other regressors in the model.[114] Logistic regression was chosen over linear regression for its utility in dividing the study population by cutpoints that are clinically significant (e.g. A1c $< 9\%$, BMI < 30, SBP < 140 mmHg). The aforementioned covariates (i.e. rural location, American Indian race, and male gender) were not available in the patient medical records and thus were derived at the block group level from the American Community Survey of the 2010 U.S. Census.[115] Block groups are the smallest units of census geography for which the detailed "long form" social and economic data from the census are tabulated.[116] They are continuous variables, representing the percentage of each block group that is American Indian, rural, or male.

Statistical analysis was conduced using R statistical software.[117] Associations between variables were examined by analyzing bivariate scatterplots in R. Two-sided significance was considered at $p<0.05$ and with the use of 95% confidence intervals.

Three bivariate analyses were conducted using multiple logistic regression. One analysis examined A1c as an outcome, another examined BMI, and the third examined SBP. The A1c variable was binary (less than 9%/greater than 9%). The cutpoint of 9% was chosen in order to align with the cutpoints used by Robeson Health Care Corporation, which uses the category of "A1c < 9%" and "A1c > 9%" when reporting patient health outcome data to the federal government. The influence of each independent variable (distance to fast food [binary, reference: less than 2 miles], distance to supermarket [binary, reference: less than 2 miles], BMI [continuous], SBP [continuous], probability of rural status [continuous], probability of male gender [continuous], and probability of American Indian race [continuous]) on A1c level was measured using logistic regression. With BMI as an outcome, the cutpoint of 30 was chosen to divide patients into one group with normal BMI (less than 30), and another group that was obese (BMI over 30). With SBP, the cutpoint of 140 was chosen to divide the patients into one group with low blood pressure (less than 140 mmHg) and another group with high blood pressure (greater than 140 mmHg).

Raw coefficient estimates were exponentiated to produce a crude odds ratio (OR), and 95% confidence intervals were calculated for the OR estimates.[118] Odds ratios were adjusted for potential confounders, which may purport the relationship between distance to food outlet and A1c level. Specifically, odds ratios were adjusted for potential confounders that may have influence on A1c level, including sex,[119] race, and rural status.

Ethical considerations

Institutional Review Board approval was obtained from the University of North Carolina at Chapel Hill for this study through a modification of an existing study. A confidentiality business agreement between the researcher and Robeson Health Care Corporation was signed.

Results

This section begins by displaying the descriptive statistics of the study population. Next, we display maps of Robeson County to visualize the study population. Then, we show the count of food outlets by township. Then, we show the proportion of study population that lives within various distances of the food outlets. Finally, we show the results of multiple logistic regression models with A1c, BP, and BMI as outcomes.

Descriptive statistics of study population

Table 2 reports the descriptive statistics of the sample of 1,297 type 2 diabetes patients that had at least one visit to the Robeson Health Care Corporation between 2010 and 2011 (see Table 1A in the appendix for more descriptive statistics).

Of the 1,297 geocoded observations, the mean A1c was 7.80 (SD 1.96), which is less than the HRSA Bureau of Primary Health Care's target for "controlled A1c" of less than or equal to 9%.[120] Figure 2A in the appendix is a box-plot showing the distribution of A1c levels among the study population. There are several outliers with A1c > 12%, and the median A1c is roughly 7% (see Figure 2A).

Of the 1,056 patients with BMI data available, the mean BMI was 34.51 (SD 7.7), which is considered obese.[121] The mean SBP was 137.70 mmHg (SD 19.30), which is just below the cutoff for high blood pressure (140 mmHg). The mean distances to food outlets were as follows: fast food restaurant: 2.62 miles (SD 1.98); supermarket: 2.31 miles (SD 1.93), convenience store: 1.41 (SD 1.18), and farmers' market: 2.70 (1.94). Because some values were missing for BMI and SBP, the total number of values for each variable is listed as (N = X).

Table 3 reports the descriptive statistics about the Robeson County population, as collected from the American Community Survey of the United States Census Bureau (2010). A significantly greater proportion of Robeson residents live in rural areas (62.6%) than in urban areas.

Table 2. Descriptive statistics for individual-level variables of 1,297 patients with at least one visit at Robeson Health Care Corporation between 2010 and 2011

Variable	N	Mean (SD)	Median
A1c level	1,297	7.80 (1.96)	7.200
BMI	1,056	34.51 (7.70)	33.310
SBP (mmHg)	1,256	137.70 (19.30)	136.000
Distance to fast food restaurant (miles)	1,297	2.63 (1.98)	2.357
Distance to supermarket (miles)	1,297	2.31 (1.93)	1.866
Distance to convenience store (miles)	1,297	1.41 (1.18)	1.148
Distance to farmers' market (miles)	1,297	2.70 (1.94)	2.150

Table 3. Descriptive statistics of aggregate-level variables for Robeson County from American Community Survey (U.S. Census Bureau, 2010).

Variable	Value
Race/ethnicity (alone or in combination)	
American Indian	35.9%
White	31.8%
Black	28.6%
Other	5.2%
Asian	0.99%
Hawaiian/Pacific Islander	0.16%
Sex	
Female	51.4%
Male	48.6%
Age	
20-29	13.8%
30-39	13.1%
40-49	13.0%
50-59	12.9%
60-69	9.3%
70+	7.4%
Age (different breakdown)	
20-44	33.2%
45-64	25.1%
>65	11.2%
Residence	
Urban	37.4%
Rural	62.6%
Family status	
Family households*	70.7%
Nonfamily households **	29.3%

* households that have at least one member of the household related to the householder by birth, marriage, or adoption; includes same-sex couple households if there is at least one additional person related to the householder by birth or adoption
** households consisting of people living alone or which do not have any members related to the householder; includes same-sex couples without children

Maps of Robeson County and the study population

A map of Robeson County labeled with names of townships from the 2000 U.S. Census can be found in the appendix (see Figure 1A).[122] Figure 3 shows a map of Robeson County overlaid with coordinates of the 1,297 patient observations, 85 fast food restaurants, 46 supermarkets, 118 convenience stores, and 24 farmers' markets. The majority of fast food restaurants and supermarkets are concentrated in the townships of Lumberton, Pembroke, Red Springs, Maxton, St. Pauls, and Fairmont. About 20 out of 29 townships did not have any fast food restaurants, while 18 out of 29 townships do not have any supermarkets.

Figure 4 shows a map of Robeson County overlaid with patients, stratified by their A1c level. Patients with A1c $< 9\%$ are represented by blue Xs, and patients with A1c $> 9\%$ are represented by red Xs.

Figure 5 shows a map of Robeson County, overlaid with patients with A1c $> 9\%$ and all the food outlets. There are clusters of patients with A1c greater than 9% residing in the townships of Lumberton, Fairmont, Red Springs, and Maxton.

Fig. 3. Map of Robeson County, NC overlaid with RHCC patient sample (black), fast food restaurants (red), supermarkets (green), and convenience stores (gold), and farmers' market (blue).

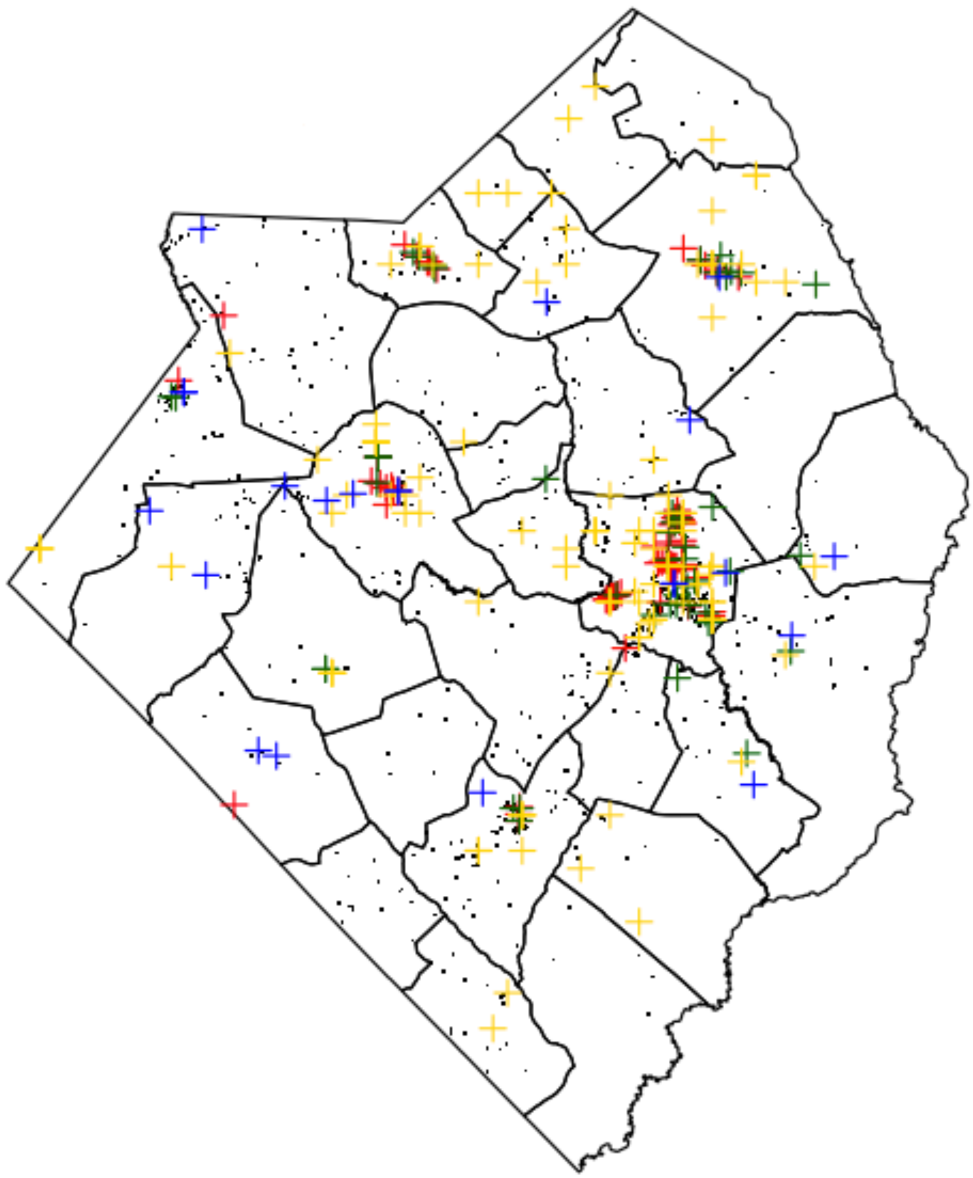


Fig. 4. Map of Robeson County, NC overlaid with RHCC patient sample with A1c < 9% (blue) and with A1c > 9% (red).

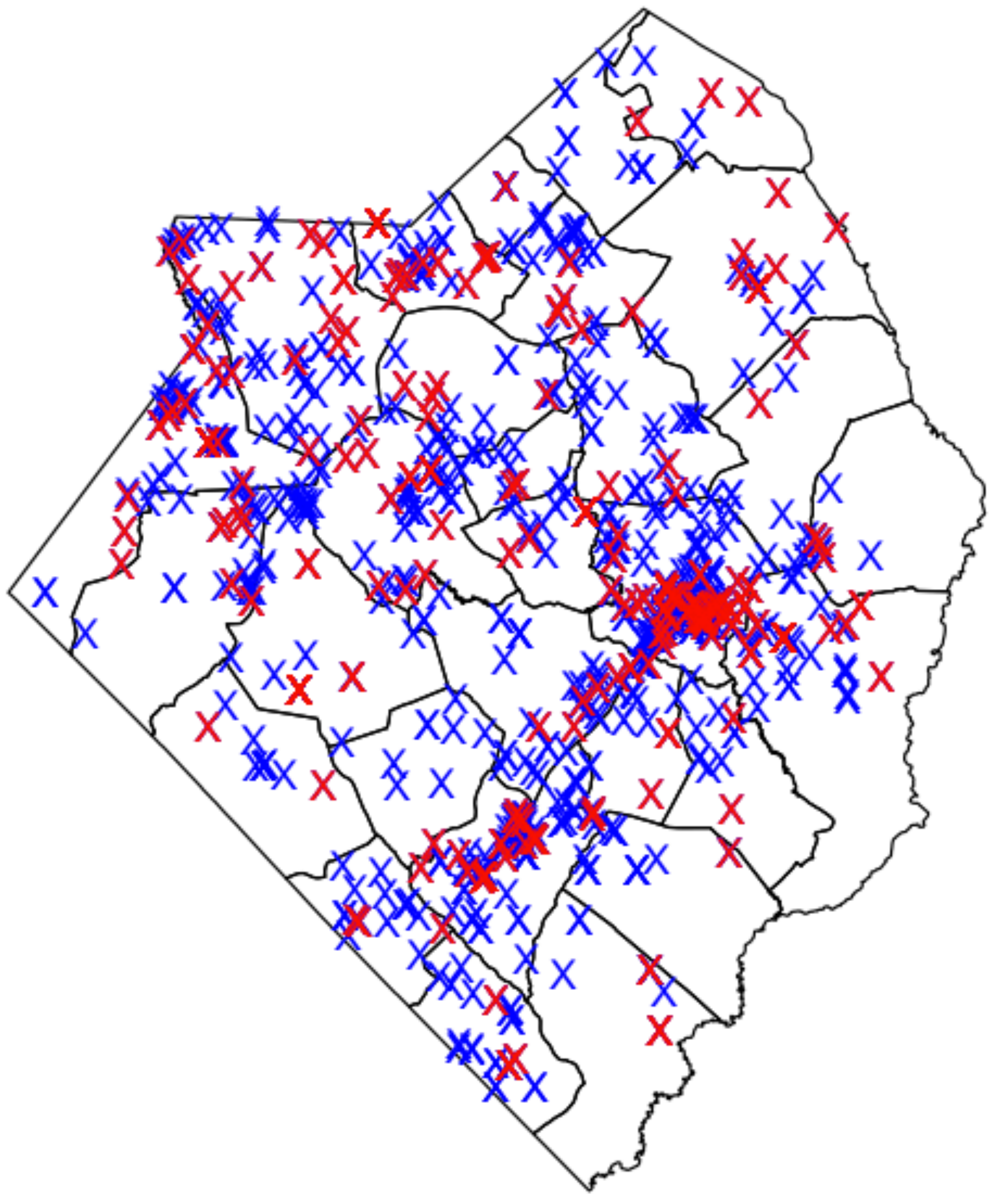
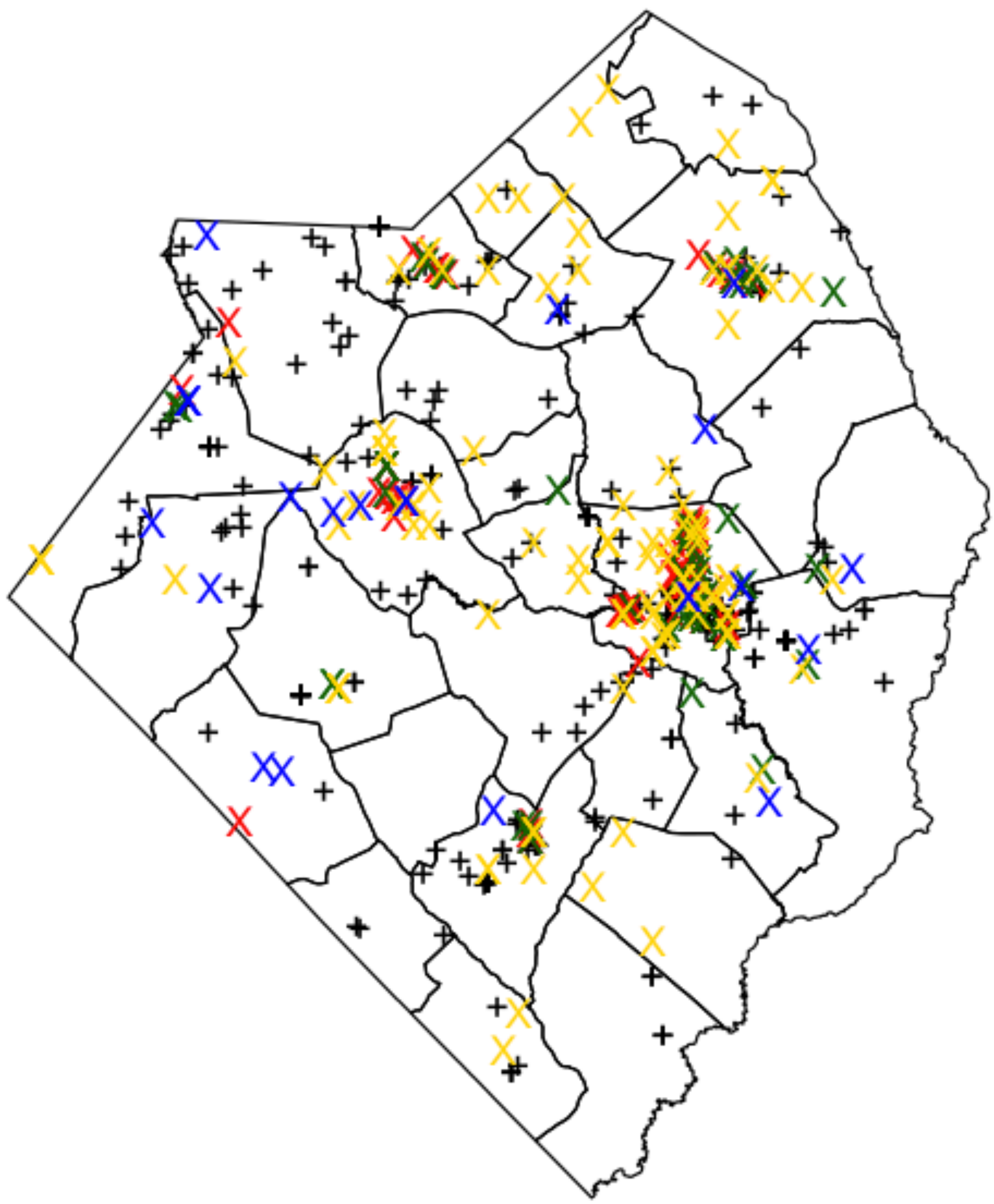


Fig. 5. Map of Robeson County, NC overlaid with RHCC patient sample with A1c > 9% (black) and fast food restaurants (red), supermarkets (green), convenience stores (gold), and farmers' market (blue).



Count of food outlets

Table 4 shows the counts of supermarkets, fast food restaurants, convenience stores, and farmers' markets by municipality in Robeson County, respectively. Table 5 shows a comparison of count of chain supermarkets to count of all supermarkets.

Table 4. Count of fast food restaurants, supermarkets, convenience stores, and farmers' markets by township.

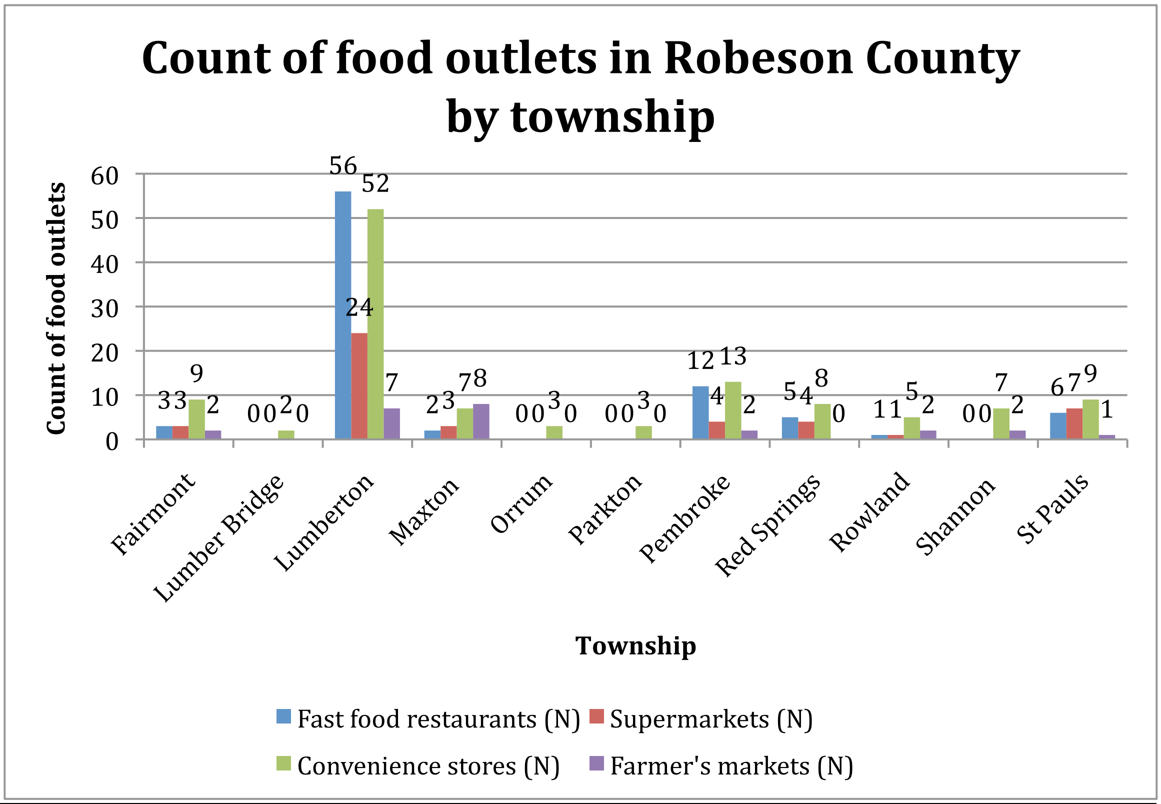
	Fast food restaurants (N)	**Supermarkets (N)**	**Convenience stores (N)**	**Farmers' markets (N)**
Fairmont	3	3	9	2
Lumber Bridge	0	0	2	0
Lumberton	56	24	52	7
Maxton	2	3	7	8
Orrum	0	0	3	0
Parkton	0	0	3	0
Pembroke	12	4	13	2
Red Springs	5	4	8	0
Rowland	1	1	5	2
Shannon	0	0	7	2
St. Pauls	6	7	9	1
Total	**85**	**46**	**118**	**24**

Table 5. Count of total and chain supermarkets in Robeson County by township.

Township	**Chain supermarkets* (N)**	**All supermarkets (N)**
Fairmont	2	3
Lumberton	12	24
Maxton	3	3
Pembroke	4	4
Red Springs	3	4
Rowland	0	1
St. Pauls	3	7
Total	**27**	**46**

*Chain supermarkets include ALDI, Bo's Food Stores, Food Lion, Lowes Foods, Piggly Wiggly, Safeway, Sam's Club, Save-a-Lot Food Stores, and Walmart.

Fig. 6. Count of food outlets in Robeson County by township.



Proximity to food outlets for study population

Table 6 shows the cumulative percentage and cumulative frequency of the study population that lives at various distances from food outlets (see appendix for histograms of distances to various food outlets). Approximately 41%, 56%, and 75% live within 2 miles of a fast food restaurant, supermarket, and convenience store, respectively. The minimum distance to closest fast food restaurants, supermarkets, convenience stores, and farmers' markets are 0.04 miles, 0.01 miles, 0.02 miles, and 0.07 miles, respectively; the maximum distances are 9.8 miles, 9.8 miles, 5.98 miles, and 10.9 miles, respectively. Convenience stores may be the most accessible food outlet for this study population, as 97% of the study population lives within 4 miles of a convenience store. Histograms displaying distances from each food outlet are reported in the appendix.

Table 6. Cumulative percentage (%) of the study population that lives equal to or less than various distances from food outlets (N = 1,297).

Distance to food outlet	**Fast food restaurants**	**Supermarkets**	**Convenience stores**	**Farmers' markets**
	Cumulative %	**Cumulative %**	**Cumulative %**	**Cumulative %**
0.5 mile	13	14	26	3
1 mile	25	27	47	19
2 miles	41	56	75	47
4 miles	79	83	97	79

Multiple logistic regression models

In this section, we report on the stepwise logistic regression models to illustrate the stepwise process of adding covariates to the model (see Table 7). We also report on the full logistic regression model, or model 4, (see Fig. 2 from "conceptual model" section) for each outcome (A1c, BMI, and SBP) in Tables 8 and 9. Because distance to closest fast food restaurant and distance to closest supermarket were highly correlated ($r = 0.80$, $p = 2.2e-16$), they were not included in the same model to avoid the risk of multicollinearity. Multicollinearity occurs when the correlations between independent variables is strong; it can increase standard errors of the coefficients.[123] Consequently, separate logistic regression models were run with 1) distance to fast food restaurants as the primary independent variable (Table 8), and 2) distance to closest supermarket as the primary independent variable (Table 9). Both Tables 8 and 9 summarize the influence that each independent variable has on the risk of having poor glycemic control (A1c > 9%), obesity (BMI > 30), or high blood pressure (SBP > 140 mmHg) in Robeson County, respectively. We ran multiple specifications of covariates and found that the models were robust. However, it is important to use caution when interpreting these results, as the race, gender, and rural variables were estimated at an aggregate-level and thus, estimates may not precisely represent the individuals in the study population.

Table 7 presents the stepwise logistic regression model results when A1c is the outcome, and distance to fast food restaurant is the primary independent variable. In unadjusted analysis, the odds of having uncontrolled A1c are 38.7% higher for individuals living within 2 miles of a fast food restaurant, compared to the odds for those who live 2 miles or further away [OR = 1.387, CI: 1.063, 1.810, Table 7].

Table 8 presents the logistic regression model results when A1c is the primary outcome, and distance to fast food is the primary independent variable. After controlling for other covariates (distance to convenience store, distance to farmers' market, AI, male, rural, SBP, and BMI), the odds of having uncontrolled A1c are 88.4% higher for individuals living within 2 miles of a fast food restaurant, compared to the odds for those who live 2 miles or further away [OR = 1.844, CI: (1.174, 2.899), $p<0.05$, Table 8]. Additionally, the odds of having uncontrolled A1c are 29.9% lower for individuals living within 1 mile of a convenience store, compared to the odds for those who live 1 mile or further away [OR = 0.701, CI: (0.483, 1.011), $p<0.10$, Table 8]. Because the remaining covariates (distance to convenience stores, BMI, SBP, American Indian race, male gender, and rural location) failed to reach the 5% significance level, we retain the null hypothesis that these covariates did not effect the A1c predictions.

Table 7. Stepwise logistic regression results using models 1, 2, 3, and 4 from the conceptual model, with A1c as outcome and distance to closest fast food restaurant as primary independent variable.

Indicator	**Model 1:** Fast food restaurants	**Model 2:** Model 1 + convenience stores + farmers' markets	**Model 3:** Model 2 +BMI + SBP	**Model 4:** Model 3 + Male + Rural + American Indian
Fast food < 2 miles	1.387** (1.063, 1.810)	1.578*** (1.125, 2.212)	1.683*** (1.154, 2.457)	1.844** (1.174, 2.899)
Convenience stores < 1 mile		0.827 (1.125, 2.212)	0.721* (0.498, 1.036)	0.701* (0.483, 1.011)
Farmers' markets > 2 miles		1.061 (0.802, 1.406)	0.950 (0.696, 1.297)	0.882 (0.636, 1.224)
BMI			1.001 (0.982, 1.020)	1.001 (0.982, 1.020)
SBP			1.003 (0.995, 1.010)	1.003 (0.995, 1.010)
Male				1 (0.999, 1.001)
Rural				1 (1.000, 1.001)
American Indian				1.001 (0.989, 1.002)

*P<0.10, **P<0.05, ***P<0.01

Table 8. Logistic regression results using full models with A1c, BMI, and SBP as outcomes, and distance to closest fast food restaurant as the primary independent variable.

	A1c > 9 OR (95% CI)	**BMI > 30 OR (95% CI)**	**SBP > 140 OR (95% CI)**
Fast food restaurants < 2 miles	1.844** (1.174, 2.899)	1.006 (0.671, 1.511)	1.039 (0.948, 1.138)
Convenience stores < 1 mile	0.701* (0.483, 1.011)	0.948 (0.687, 1.310)	1.001 (0.930, 1.077)
Farmers' markets > 2 miles	0.882 (0.636, 1.224)	1.054 (0.785, 1.413)	1.029 (0.964, 1.100)
A1c	-	-	0.996 (0.981, 1.012)
BMI	1.001 (0.982, 1.020)	-	1.003* (0.999, 1.007)
SBP	1.003 (0.995, 1.010)	-	-
Male	1 (0.999, 1.001)	1.000 (0.999, 1.001)	1.000 (1.000, 1.000)
Rural	1 (1.000, 1.001)	1.000 (1.000, 1.000)	1.000 (1.000, 1.000)
American Indian	1.001 (0.989, 1.002)	0.945 (1.000, 1.012)	1.001 (0.999, 1.002)

*P<0.10, **P<0.05, ***P<0.01

Note: The dependent variables in these analyses are A1c coded so that 0 = A1c > 9% and 1 = A1c < 9%; BMI coded so that 0 = BMI > 30 and 1 = BMI < 30; and SBP coded so that 0 = SBP > 140 mmHg and 1 = SBP < 140 mmHg.

Table 9. Logistic regression results using full models with A1c, BMI, and SBP as outcomes, and distance to closest fast food restaurant as the primary independent variable.

	A1c > 9	BMI > 30	SBP > 140
Supermarkets > 2 miles	0.919 (0.628, 1.348)	1.060 (0.752, 1.494)	0.967 (0.700, 1.338)
Convenience stores < 2 miles	0.867 (0.621, 1.206)	0.949 (0.708, 1.274)	1.061 (0.800, 1.406)
Farmers' markets > 2 miles	0.861 (0.603, 1.231)	1.028 (0.743, 1.419)	1.123 (0.827, 1.528)
A1c	-	-	0.987 (0.924, 1.053)
BMI	1.001 (0.982, 1.021)	-	1.014* (0.997, 1.030)
SBP	1.003 (0.995, 1.011)	-	-
Male	1.000 (1.000, 1.001)	1.000 (1.000, 1.001)	1.001* (1.000, 1.001)
Rural	1.000 (1.000, 1.001)	1.000 (1.000, 1.000)	1.000 (0.999, 1.000)
American Indian	0.996 (0.990, 1.003)	1.006** (1.000, 1.012)	1.003 (0.997, 1.009)

*P<0.10, **P<0.05, ***P<0.01

Note: The dependent variables in these analyses are A1c coded so that 0 = A1c > 9% and 1 = A1c < 9%; BMI coded so that 0 = BMI > 30 and 1 = BMI < 30; and SBP coded so that 0 = SBP > 140 mmHg and 1 = SBP < 140 mmHg.

When obesity (BMI > 30) was the outcome, we did not observe that distance to closest fast food restaurant (Table 8) or distance to closest supermarket (Table 9) or other covariates had an effect on BMI predictions. Table 9 shows that, when distance to closest supermarket was the primary independent variable, the covariate of American Indian race was statistically significant (p<0.05). This may suggest that a one-unit increase in the percentage of American Indian residents per block group is associated with an increase of 0.006 in the odds that of being obese among type 2 diabetes patients [OR = 1.006, CI:

(1.000, 1.012), Table 9]. However, this odds ratio is not clinically meaningful enough to warrant further discussion.

Similarly, when systolic blood pressure (SBP > 140 mmHg) was the outcome, we did not observe that distance to closest fast food restaurant (Table 8) or distance to closest supermarket (Table 9) or other covariates had a statistically significant effect on BMI predictions.

Discussion

The purpose of this study was to investigate whether or not there is a relationship between proximity to various food outlets and diabetes risk factors among type 2 diabetes patients in Robeson County, North Carolina.

We found that type 2 diabetes patients who live within 2 miles of fast food restaurants have slightly greater odds than other type 2 diabetes patients of having uncontrolled A1c, but do not have significantly higher odds of being obese or having high blood pressure. In contrast, type 2 diabetes patients living within 1 mile of a convenience store had slightly *lower* odds than other type 2 diabetes patients of having uncontrolled A1c.

We found no relationship between A1c levels and proximity to supermarkets, convenience stores, or farmers' markets. However, the relationship between A1c and proximity to fast food restaurants remained even when we added other food outlets to the analysis. We also found no relationship between proximity to any of the food outlets (fast food restaurants, supermarkets, convenience stores, and farmers' market) and BMI or SBP.

While evidence exists to suggest a positive association between A1c and high blood pressure, recent studies suggest that this relationship is diminished with the adjustment for BMI.[124] This suggests that the relationship between BMI and blood pressure may be of more importance than the relationship between A1c and blood pressure. Past literature shows that BMI and blood pressure are usually have a positive association.[125,126,127,128] Our study was consistent with the literature in finding that the correlation between BMI and blood pressure was positive, although it was very weak.

Similarly, we noted that there was a positive correlation between A1c and blood pressure, but it was also very weak.

There is also evidence that BMI is positively associated with A1c,[129,130] and that BMI reduction is associated with A1c reduction.[131] Again, our study was consistent with the literature in finding that the correlation between BMI and A1c was positive, albeit very weak and not statistically significant.

The weak correlations between BMI and SBP, and BMI and A1c could be attributed to the presence of outliers in the dataset (i.e. many patients with extremely high BMIs that ranged from 50 to 70). It is known that weight loss is more difficult for type 2 diabetes patients compared to non-diabetic patients, which could explain why there are so many patients with very high BMIs in this study population.[132] Additionally, it is possible that patients may be taking medication to control their A1c, but are still obese due to lack of physical activity, poor diet, genetics, or some combination of those factors. Future research should explore specifically why the correlations between these variables in this study population are so weak.

Food environment

Our findings are not consistent with the literature that suggests that rural residents tend to live more than 10 miles from the nearest supermarket.[133] Instead, our study found that patients in the study population live, on average, 2.3 miles from the nearest supermarket. Our findings are consistent with Sharkey et al.'s study of the food environment in rural Texas, which found that distance to the nearest convenience store, which they call "non-traditional fast food outlet," was closer than distance to the nearest fast food restaurant.[134] The average patient in our study population lived about around 2.6

miles from a fast food restaurant and 1.5 miles from a convenience store, which is less distance than in Sharkey et al.'s study.[135] The maximum distance to a fast food restaurant, supermarket, or farmers' market was 10 miles, but over 75% of the sample lived within 4 miles of all food outlets.

Although the mean distance to the closest fast food restaurant was slightly higher than mean distance to the closest supermarket, there were nearly twice as many fast food restaurants in the county as there were supermarkets, and nearly 4 times as many fast food restaurants as farmers' markets. Despite the fact that many patients do live geographically nearby to many food outlets, it is important to note that there are nearly 2.5 times as many fast food restaurants as there are supermarkets in Lumberton, and 3 times as many fast food restaurants as there are supermarkets in Pembroke. Lumberton has the most supermarkets and the most fast food restaurants of all the municipalities in Robeson County. However, there more than double the number of fast food restaurants as there are supermarkets. Pembroke also has three times as many fast food restaurants as supermarkets, though there are fewer overall food outlets than in Lumberton.

We found that convenience stores may be the most accessible food outlets for this sample population in Robeson County. Some evidence exists that convenience stores are less likely to sell foods that are recommended for diabetics, such as low-fat milk, high-fiber bread, or fresh fruits and vegetables.[136] Instead, they commonly sell foods that are high-caloric, low-nutrient foods. There is potential for public health practitioners to intervene at the convenience store level by working with storeowners to introduce healthier food in these stores. Several studies have documented successful interventions in increasing access to fruits and vegetables in convenience stores, corner stores, and Hispanic *tiendas*.[137,138,139]

Comparison with other studies

Our findings are consistent with past evidence supporting the idea that proximity to fast food restaurants is associated with unhealthy behaviors and poor health outcomes (such as A1c level). Rothman et al. found that fast food consumption, for which proximity is a proxy, is associated with uncontrolled A1c level among adolescents.[140]

Although our results did not show a relationship between proximity to fast food and BMI, several studies have documented these relationships.[141,142,143,144] However, there are mixed results about the relationship between these variables; one systematic review found six studies that found associations, and four studies that found no association.[145] Giskes et al. suggests that the macro-level food environment, which has been defined as "access to food venues such as supermarkets and fast food restaurants,"[146] may be a causal factor—albeit distal—in the pathway to poor diet and obesity.[147]

Our result that proximity convenience store is associated with better health outcomes (i.e. A1c control) is not consistent with past research that examined this association.[148,149] Further research is needed to better understand why proximity to convenience stores may be associated with better A1c control. Additionally, our finding that proximity to supermarkets is not associated with reduced obesity is inconsistent with previous studies, which did find existence of an association.[150,151]

Implications for primary care practices

When providing care to patients with type 2 diabetes or related metabolic disorders, primary care providers should inform patients about the need for a healthy diet. Specifically, patient education can include information relevant to Robeson County regarding details such as locations of healthy food outlets or contact information for farmers' markets and produce stands. As there are several supermarkets and farmers' markets in Robeson County, particularly in Lumberton, clinicians should encourage their at-risk patients to shop for healthier food options at these locations and avoid unhealthy foods from fast food restaurants or convenience stores. Primary care practices can also employ community health workers (CHW) to provide dietary counseling. Studies have shown that interventions with CHW support can improve dietary behavior scores[152] and increase the number of patients eating five fruits and vegetables per day.[153] However, it is important to note that practices may not be able to afford this type of personalized counseling.

Implications for policy-makers

This study has several implications regarding zoning decisions for policy-makers to consider. Understanding the geography of diabetes distribution can help public health practitioners prioritize where to implement healthy food and physical activity interventions. For example, given that Lumberton is the municipality with both the largest population and also the highest number of fast food restaurants in the county, the Robeson County Health Department could focus on launching public health programs in Lumberton. Local officials in Robeson County could consider a range of policy options to reduce unhealthy food consumption, from levying fees on stores that sell sugar-sweetened beverages[154] to requiring calorie labeling on menus in restaurants.[155]

Given that there is less access to farmers market compared to other food outlets, Robeson County policy-makers can improve zoning ordinances in a manner that increases access to farmers markets and produce stands. According to unpublished data, Robeson County has six municipalities that have received a healthful food zoning (HFZ) score, which is calculated by evaluating various elements of the zoning ordinance that are supportive of healthful food outlets.[156] Municipalities with zoning ordinances that permit healthful food outlets, such as farmers' markets and produce stands, received more points than municipalities that prohibited them.[157] HFZ scores ranged from 0 to 1, with a higher score indicating healthier food zoning.[158] HFZ scores range from 0.14 (Rowland) to 0.48 (Raeford), with this order from lowest to highest HFZ score: Rowland, St. Pauls, Lumberton, Fairmont, Pembroke, and Raeford.[159] The mean HFZ score for Robeson County is 0.21,[160] which is below the regional average of 0.33 from northeastern North Carolina counties.[161] Unpublished data suggests that the existence of farmers' markets and produce stands is often prohibited in residential zones, but is often permitted in agricultural zones and sometimes in commercial or industrial zones.[162] Local health department officials should take steps to improve the HFZ score for Robeson County in order to promote access to healthy food. Further research is needed to determine whether there are specific zoning ordinances in Robeson County that prohibit healthful food outlets like farmers markets or produce stands, and whether zoning is strictly enforced throughout the county.

Limitations

There are a few limitations based on the study design. Because this was a cross-sectional design, we only analyzed data from a specific cohort of type 2 diabetes patients in Robeson County. As a clinic-based sample, this study does not account for patients with type 2 diabetes who receive care at other clinics nor those who do not receive any care. Moreover, because this was an observational study, we cannot conclude that the reported associations between proximity to fast food restaurants and uncontrolled A1c control are causal.

The dataset used for this analysis poses some additional limitations. The outcome measures (A1c, blood pressure, and BMI) used for this study are from 2010-2011, and thus findings may not represent the most recent measures from Robeson Health Care Corporation patients. Another limitation is that some patients may have attended the clinic more than once between 2010 and 2011, and thus there may be multiple records of A1c, BMI, and blood pressure for one patient. Potential bias may have been introduced by the multiple observations, as this violates the statistical assumption of independence. Effectively, the presence of multiple observations may skew the logistic regression data in the direction of the values of the multiple observations.

There are a few limitations related to the outcome variable of A1c, which has limits as a measure of diabetes control. Although A1c provides a more stable measure of diabetes control than fasting glucose measures,[163] a limitation is that A1c levels may vary when tested in one lab compared to another.[164] Furthermore, A1c may be falsely low for individuals who experience heavy or chronic bleeding, or had a recent blood transfusion; conversely, A1c may be falsely high for individuals who do not have enough iron in their bloodstream.[165]

With spatial data analysis, direct observation of locations (i.e. food outlets) is considered the ideal methodology for ground-truthing,[166] Due to lack of time, we conducted ground-truthing via telephone calls and web searches. Moreover, it is important to note that ReferenceUSA, the public database used to retrieve food outlet addresses, may not be comprehensive, or may over- or underestimate the number of food outlets present in Robeson County.[167]

There are several limitations to only using proximity as a measure of food access. Other studies that evaluate food access have also examined ratio,[168] density, and coverage of food outlets.[169,170] Proximity is one predictor of food access among many other complex predictors—including individual food preferences, access to transportation, cost of food, availability of food, and ability to prepare and cook healthy food—that are not accounted for in this study. GIS data can yield significant information about the food environment, but it seldom sheds light on consumer behavior. Proximity to certain food outlets does not necessitate that an individual will purchase food from or eat at that location. As such, proximity to supermarkets or farmers' markets does not indicate whether or not individuals will buy fresh produce or other healthy options. It is also important to remember that supermarkets carry many unhealthy products that can be purchased as cheaply as fast food. One limitation of including smaller grocery stores in the "supermarket" category of this study is that these small stores may not have the same consistent access to fresh fruits and vegetables that is often associated with chain supermarkets.

This study considered a limited cross-section of the food environment; thus, we did not examine other food outlets, such as full-service restaurants, dollar stores and discount stores, pharmacies and drug stores, specialty food stores (e.g. meat markets, fish and seafood markets, etc.) or other non-traditional food venues. In addition, this study did not consider more informal food sources, such as food received through family networks or from faith-based organizations.

Although this analysis controlled for some biological and demographic characteristics, residual confounding may exist from other variables, such as socioeconomic status,[171] access to transportation,[172],[173] or use of medications.[174] Additionally, this study did not control for the "intermediate risk factors," such as fast food purchasing and consumption, physical activity, and genetics, which may be mediating factors in the relationship between proximity to food outlets and proximal risk factors like A1c, BMI, and blood pressure.

Strengths

Strengths of this study including having a large sample of type 2 diabetes patients. Additionally, this research is community-based and responds to the needs of a community health center and vulnerable patient population in Robeson County. As mentioned in the introduction, the prevalence of type 2 diabetes in Robeson County is higher than the North Carolina and national average, and a key issue to address for the health of American Indians and other minority populations. This is the first study to examine the relationship between proximity to food venues and A1c level, in addition to BMI and SBP, for this specific patient population in Robeson County. Furthermore, while there have been a few studies using GIS for environmental studies in Robeson County, GIS mapping has never been applied for the purpose of understanding the food environment in Robeson County. GIS mapping is an innovative tool with many practical applications for primary care and public health practitioners in preventing and combating diabetes and other chronic diseases.

Future research

Future research should address the limitations stated above, by having unique observations of patients, including more diverse and non-traditional food outlets in the analysis, and considering other aspects of food access, such as coverage and density. Further studies should further investigate whether socioeconomic status and access to transportation are important covariates in the pathway between proximity to food outlets and diabetes risk factors. In order to paint a fuller picture of the food environment, future investigations should incorporate quantitative data regarding individuals' food preferences and shopping behaviors into studies about access to food outlets. Additionally, qualitative research should explore whether proximity to food outlets is a significant determinant of shopping behaviors. There is also potential for comparative investigation of food environments across different North Carolina counties to inform state policy-makers of disparities in food access, and ultimately position policy-makers to allocate scarce resources where health outcomes are the poorest.

Appendix

Table 1A: Descriptive statistics of study population.

A1c Levels (N = 1,297)	
Minimum	4.7
1st quartile	6.4
Median	7.2
Mean	7.8
3rd quartile	8.7
Maximum	16.7
A1c Control (N = 1,297)	
Less than 7% (strict control)	43.5% (N = 564)
Between 7-8% (control)	19.8% (N = 257)
Between 8-9% (borderline control)	13.6% (N = 177)
Greater than 9% (uncontrolled)	23.1% (N = 299)
A1c Controlled vs. Uncontrolled	
Less than 9% (controlled)	76.9%
Greater than 9% (uncontrolled)	23.1%
BMI (N = 1,056)	
Underweight (below 18.5)	0.09% (N = 1)
Normal (18.5 to 24.9)	7.67% (N = 81)
Overweight (25 to 29.9)	23.0% (N = 243)
Obese (30 to 40)	48.58% (N = 513)
Morbidly obese (above 40)	20.64% (N = 218)
SBP	
Distance to Closest Fast Food Restaurant (miles)	
Min	0.04
Median	2.36
Mean	2.63
Max	9.79
Distance to Closest Supermarket (miles)	
Min	0.01
Median	1.87
Mean	2.31
Max	9.8
Distance to Closest Convenience Store (miles)	
Min	0.03
Median	1.15
Mean	2.00
Max	5.98
Distance to Closest Farmers' Market (miles)	
Min	0.01
Median	2.16
Mean	2.78
Max	10.9

Table 2A. Pearson's correlation coefficients between diabetes risk factors.

	Pearson's correlation coefficient	**P-value**
BMI, SBP	0.094	0.002
A1c, SBP	0.059	0.036
BMI, A1c	0.008	0.784

Fig. 1A. Map of Robeson County with township labels.

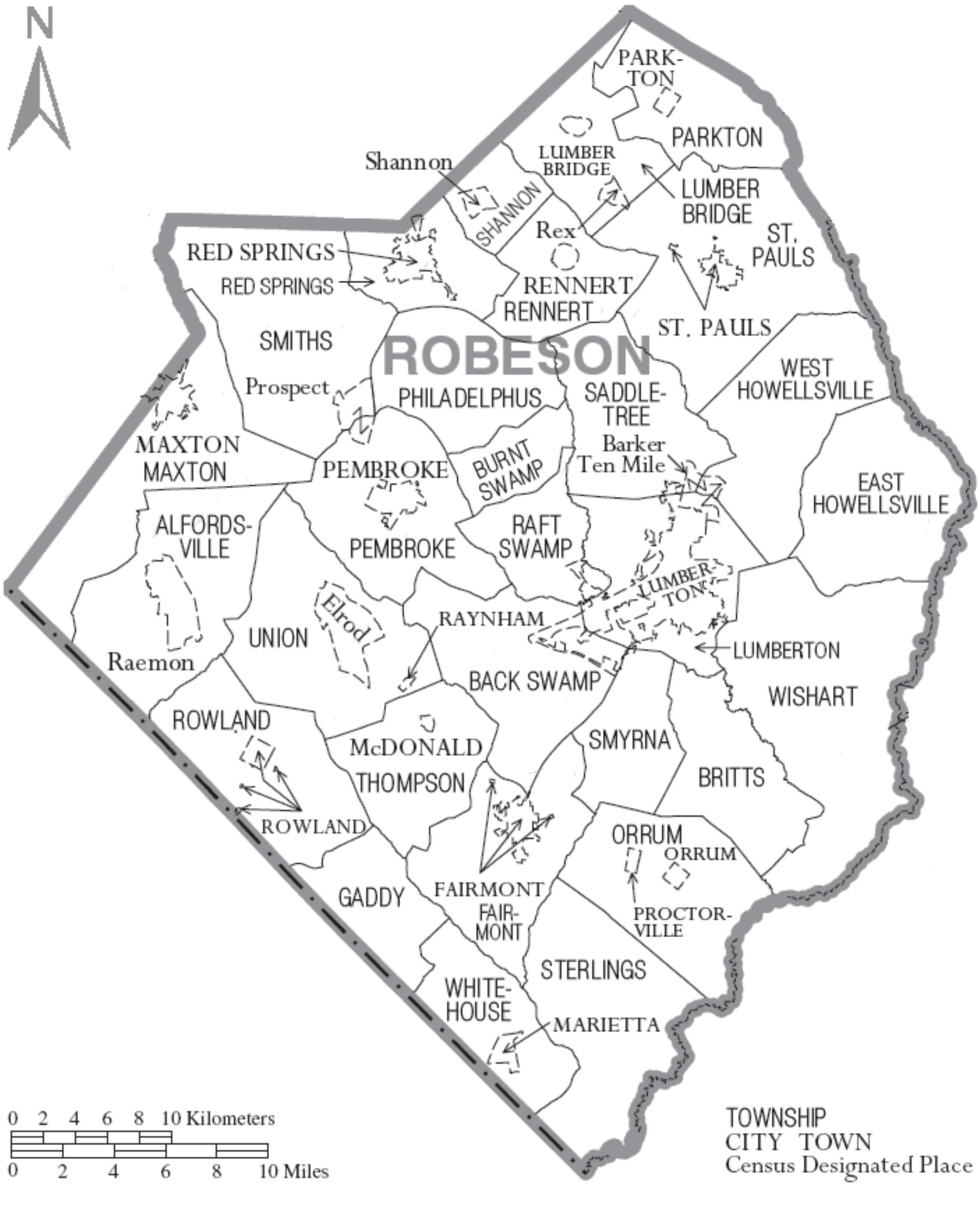


Fig. 2A. Box-plot of A1c levels (%) among 1,297 patient observations from RHCC between 2010 and 2011.

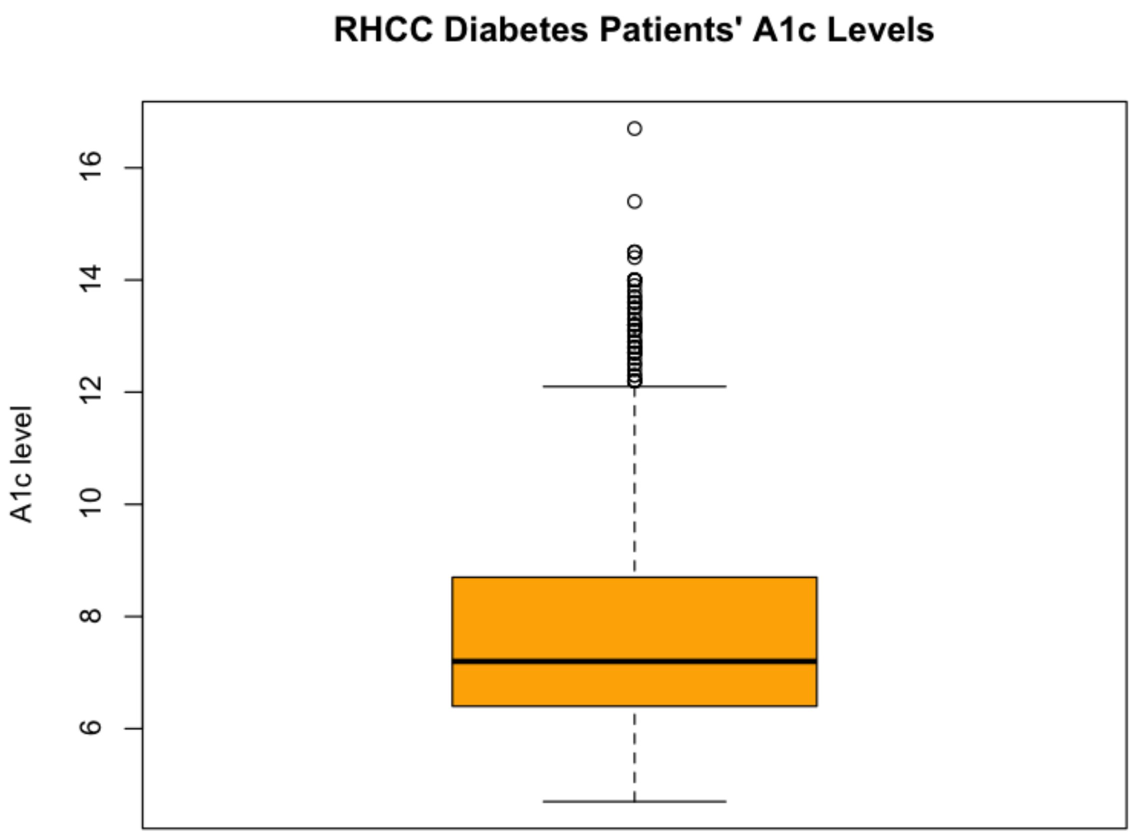


Fig. 3A. Histogram of distance to closest fast food restaurant in miles (N = 1,297).

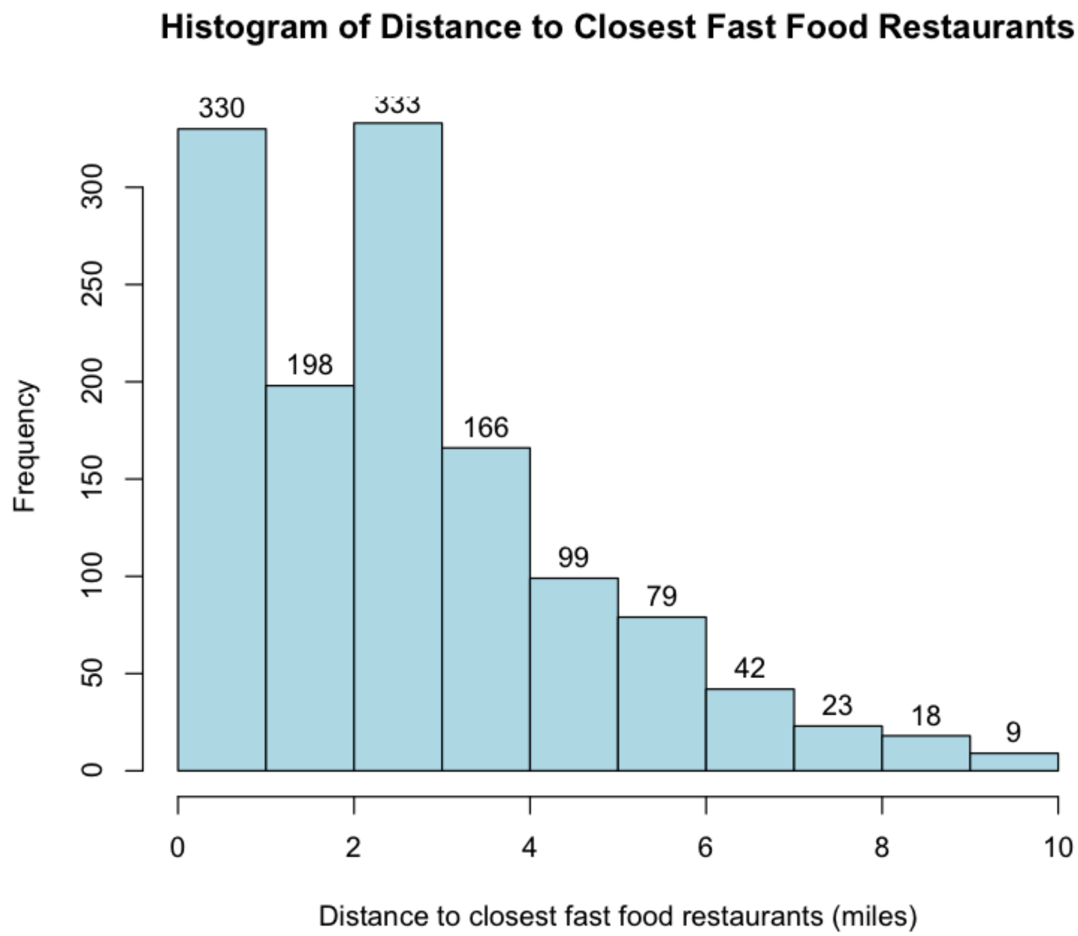


Fig. 4A. Histogram of distance to closest supermarket in miles (N = 1,297).

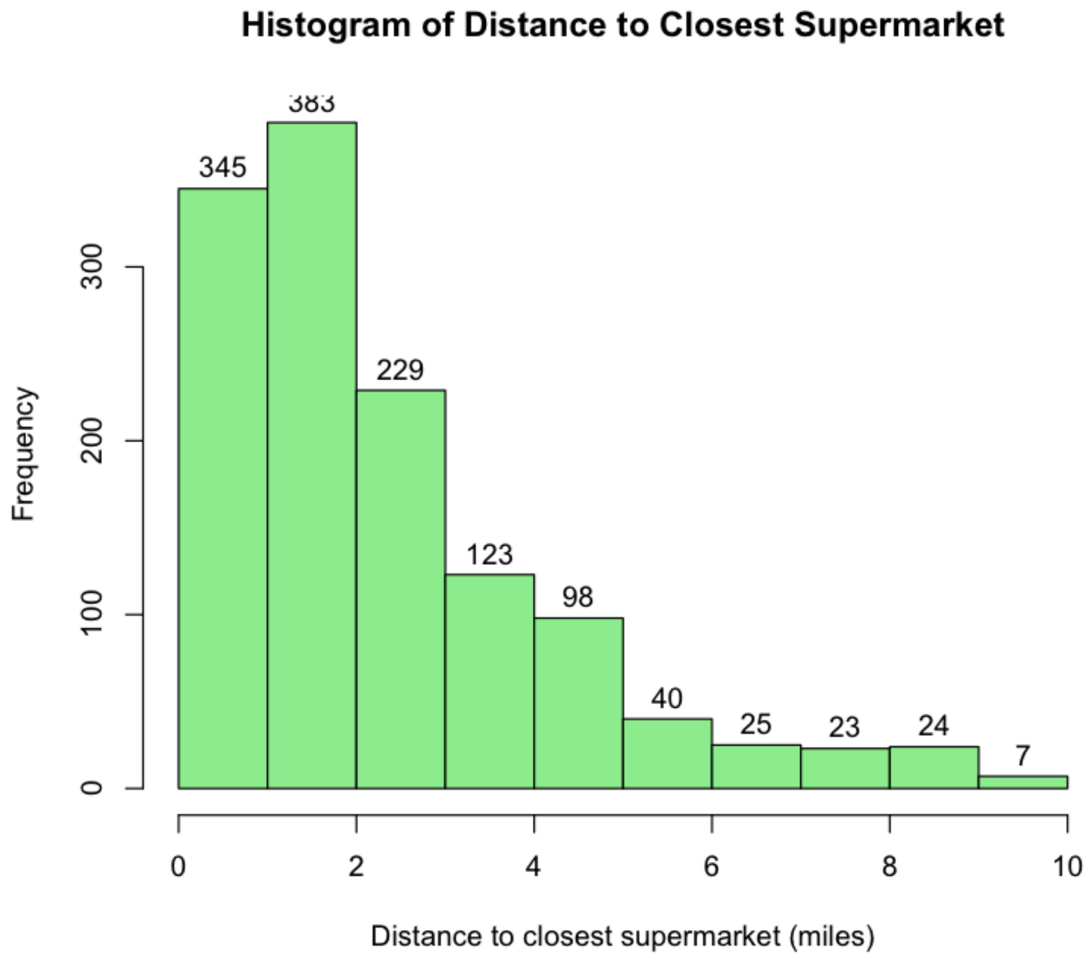


Fig. 5A. Histogram of distance to closest convenience store in miles (N = 1,297).

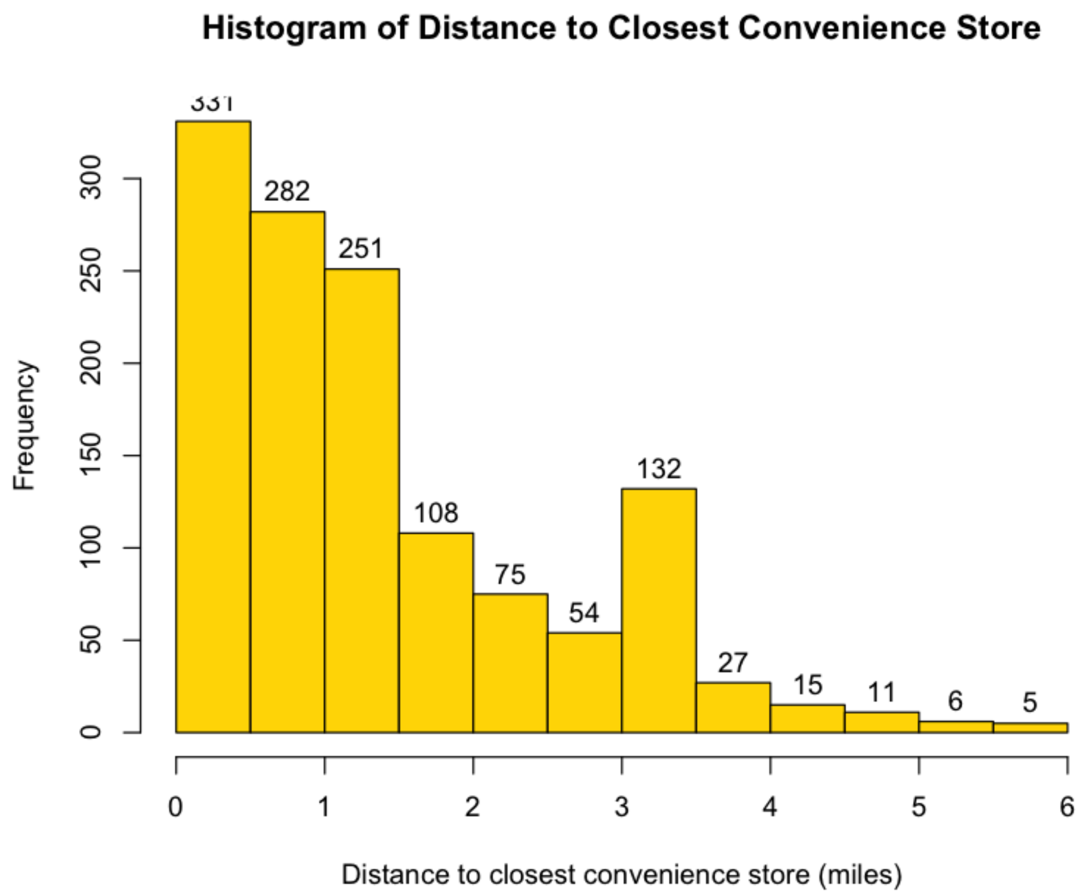


Fig. 6A. Histogram of distance to closest farmers' market in miles (N = 1,297).

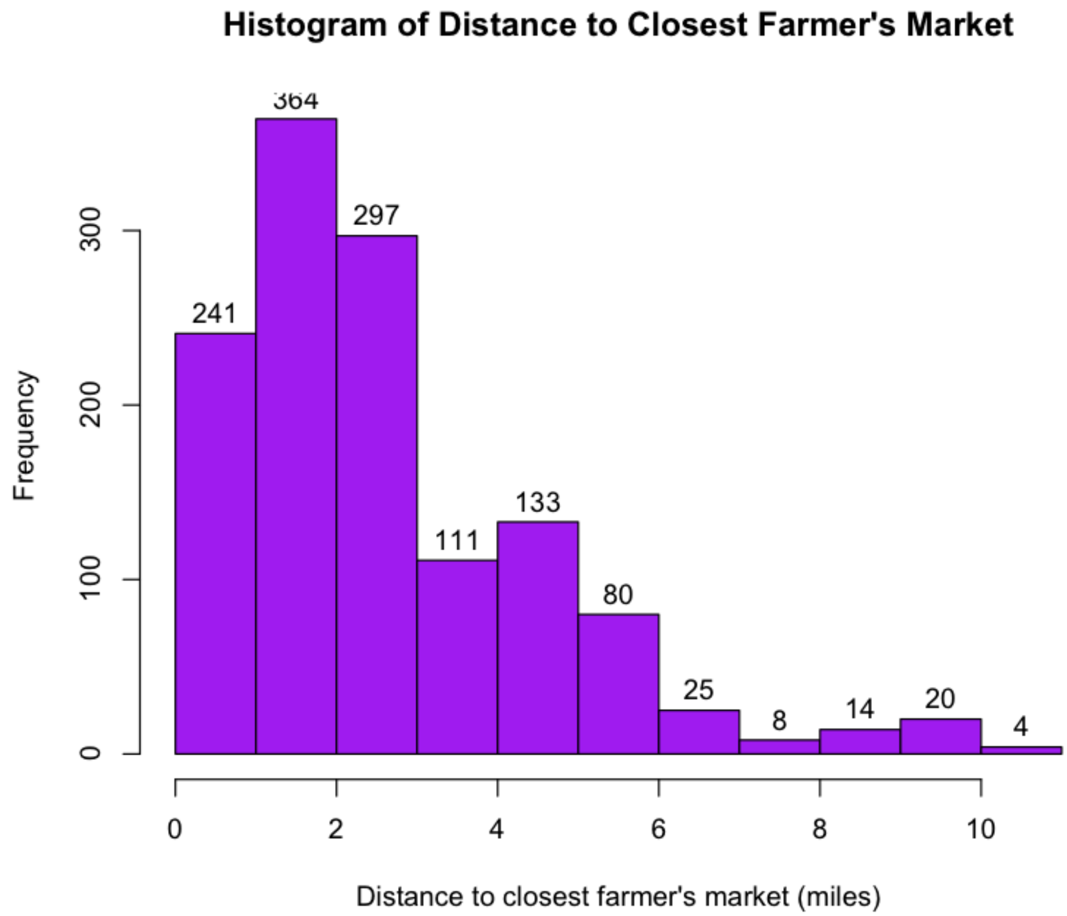
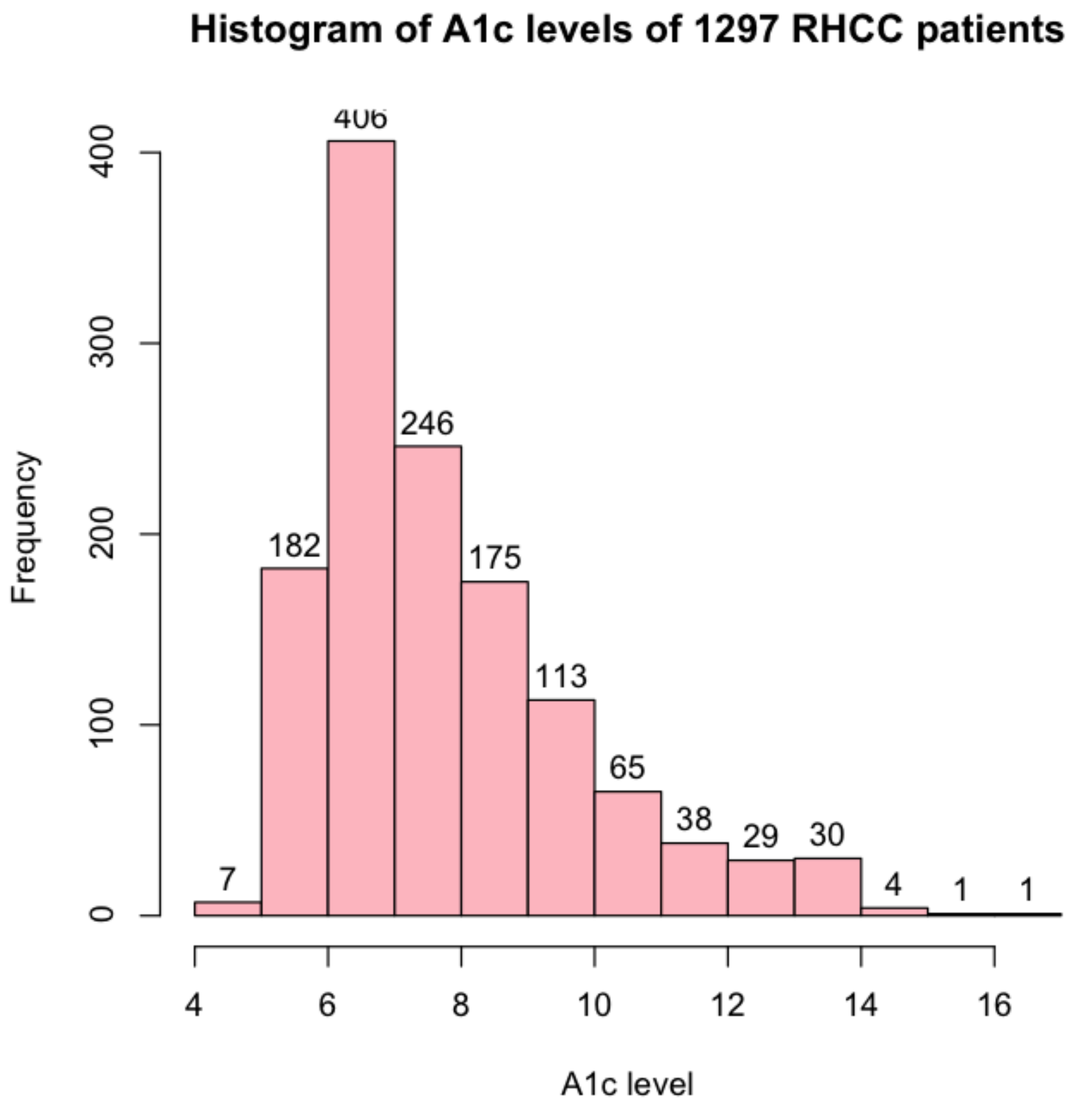


Fig. 7A. Histogram of A1c levels (N = 1,297).



Level of control	% of study population	N
Strict control (< 7)	46	595
Control (7-8)	19	246
Borderline control (8–9)	13	175
Uncontrolled (>9)	22	281

References:

[1] Centers for Disease Control and Prevention. (2011). National Diabetes Fact Sheet, 2011. Atlanta, GA: Centers for Disease Control, U.S. Department of Health and Human Services. Retrieved from http://www.cdc.gov/diabetes/pubs/pdf/ndfs_2011.pdf.
[2] Centers for Disease Control and Prevention. (2012.) Diabetes Report Card, 2012. Atlanta, GA: Centers for Disease Control, U.S. Department of Health and Human Services. Retrieved from: http://www.cdc.gov/diabetes/pubs/pdf/diabetesreportcard.pdf.
[3] Centers for Disease Control and Prevention. (2011). Successes and Opportunities for Population-Based Prevention and Control at a Glance. Atlanta, GA: Centers for Disease Control, U.S. Department of Health and Human Services. Retrieved from http://www.cdc.gov/chronicdisease/resources/publications/AAG/ddt.htm.
[4] North Carolina Department of Health and Human Services, Division of Public Health. (2008). The Burden of Diabetes in North Carolina: Prevalence, Complications, and Costs. Retrieved from http://cdm16062.contentdm.oclc.org/cdm/ref/collection/p249901coll22/id/637321.
[5] Robeson County 2011 Community Health Assessment. (2011). Lumberton, NC: Robeson County Health Department. Retrieved from http://publichealth.southernregionalahec.org/robeson/report.html.
[6] Konen, J. & Page, J. (2012). The State of Diabetes in North Carolina. *North Carolina Medical Journal*, 72(5):373-378.
[7] Larson, N. I., Story, M. T., & Nelson M. C. (2009). Neighborhood Environments: Disparities in Access to Healthy Foods in the U.S. *American Journal of Preventive Medicine,* 36(1), 74-81.
[8] Ibid.
[9] Beaulac, J., Kristjansson, E., & Cummins, S. (2009). A systematic review of food deserts, 1966-2007. *Preventing Chronic Disease,* 6(3), 1-10.
[10] Powell, L., Slater, S., Mirtcheva, D., et al. (2007). Food store availability and neighborhood characteristics in the United States. *Preventive Medicine,* 44, 189-195.
[11] American Diabetes Association. (2013). Diabetes Meal Plans and a Healthy Diet. Retrieved from http://www.diabetes.org/food-and-fitness/food/planning-meals/diabetes-meal-plans-and-a-healthy-diet.html.
[12] Centers for Disease Control and Prevention. (2008). Preventing Chronic Diseases: Investing Wisely in Health. Atlanta, GA: Centers for Disease Control, U.S. Department of Health and Human Services. Retrieved from http://www.cdc.gov/nccdphp/publications/factsheets/prevention/pdf/diabetes.pdf.
[13] Bell, R.A. (2011). Barriers to diabetes prevention and control among American Indians. North Carolina Medical Journal, 72(5), 393-396.
[14] Beaulac, J., Kristjansson, E., & Cummins, S. (2009). A systematic review of food deserts, 1966-2007. *Preventing Chronic Disease,* 6(3), 1-10.
[15] U.S. Census Bureau. (2013). Robeson County, North Carolina. Retrieved from: http://quickfacts.census.gov/qfd/states/37/37155.html.
[16] Barger, S. (2012). An Overview of Diabetes in Robeson County, NC (white paper, University of North Carolina-Chapel Hill).
[17] Jilcott, S. B., Wu, Q., McGuirt, J.T., et al. (2013). Associations between access to farmers' markets and supermarkets, shopping patterns, fruits and vegetable consumption

and health indicators among women of reproductive age in eastern North Carolina, USA. *Public Health Nutrition,* 16(11), 1944-1952.

[18] American Diabetes Assocation. (2004). Diagnosis and classification of diabetes mellitus. *Diabetes Care,* 27(1), S5-S10.

[19] Konen, J. & Page, J. (2012). The State of Diabetes in North Carolina. *North Carolina Medical Journal*, 72(5):373-378.

[20] Ibid.

[21] Centers for Disease Control and Prevention. (2012). Diabetes Report Card, 2012. Atlanta, GA: Centers for Disease Control, U.S. Department of Health and Human Services. Retrieved from: http://www.cdc.gov/diabetes/pubs/pdf/diabetesreportcard.pdf.

[22] American Diabetes Assocation. (2004). Diagnosis and classification of diabetes mellitus. *Diabetes Care,* 27(1), S5-S10.

[23] National Center for Health Statistics. (2012). Deaths: Preliminary Data for 2011. *National Vital Statistics Reports*, 61(6), 1-52.

[24] American Diabetes Association. (2013). The Cost of Diabetes. Retrieved from http://www.diabetes.org/advocate/resources/cost-of-diabetes.html.

[25] Zhuo, X., Zhang, P., & Hoerger, T. J. (2013). Lifetime direct medical costs of treating type 2 diabetes and diabetic complications. *American Journal of Preventive Medicine,* 45(3), 253-261.

[26] Centers for Disease Control and Prevention. (2011). National Diabetes Fact Sheet. Atlanta, GA: Centers for Disease Control, U.S. Department of Health and Human Services. Retrieved from http://www.cdc.gov/diabetes/pubs/pdf/ndfs_2011.pdf.

[27] Centers for Disease Control and Prevention. (2011). CDC identifies diabetes belt. Atlanta, GA: Centers for Disease Control, U.S. Department of Health and Human Services. Retrieved from http://www.cdc.gov/diabetes/news/docs/diabetes_belt.htm.

[28] Ibid.

[29] Betancourt, J. R., Duong, J. V., & Bondaryk, M.R. (2012). Strategies to Reduce Diabetes Disparities: An Update. *Current Diabetes Report*, 12, 762-768.

[30] Centers for Disease Control and Prevention. (2011). National Diabetes Fact Sheet. Atlanta, GA: Centers for Disease Control, U.S. Department of Health and Human Services. Retrieved from http://www.cdc.gov/diabetes/pubs/pdf/ndfs_2011.pdf.

[31] Betancourt, J. R., Duong, J. V., & Bondaryk, M.R. (2012). Strategies to Reduce Diabetes Disparities: An Update. *Current Diabetes Report*, 12, 762-768.

[32] Centers for Disease Control and Prevention. National Diabetes Surveillance System. Atlanta, GA: Centers for Disease Control, U.S. Department of Health and Human Services. Retrieved from http://apps.nccd.cdc.gov/DDT_STRS2/CountyPrevalenceData.aspx?mode=DBT.

[33] Ibid.

[34] Robeson County 2011 Community Health Assessment. (2011). Lumberton, NC: Robeson County Health Department. Retrieved from http://publichealth.southernregionalahec.org/robeson/report.html.

[35] Ibid.

[36] Ibid.

[37] Barger, S. (2012). An Overview of Diabetes in Robeson County, NC (white paper, University of North Carolina-Chapel Hill).

[38] U.S. Census Bureau. Robeson County, North Carolina. 2013. Retrieved from: http://quickfacts.census.gov/qfd/states/37/37155.html.
[39] Ibid.
[40] National Institute of Diabetes and Digestive and Kidney Diseases. What I need to know about Eating and Diabetes. NIH Publication No. 08-5043. Bethesda, MD: National Diabetes Information Clearinghouse. 2007. Retrieved from http://diabetes.niddk.nih.gov/dm/pubs/eating_ez/#eat.
[41] HbA1c. MedlinePlus. Bethesda, MD: U.S. National Library of Medicine. 2012. Retrieved from http://www.nlm.nih.gov/medlineplus/ency/article/003640.htm.
[42] National Institute of Diabetes and Digestive and Kidney Diseases. Diabetes, heart disease, and stroke. NIH Publication No. 13-5094. Bethesda, MD: National Diabetes Information Clearinghouse. Retrieved from http://diabetes.niddk.nih.gov/dm/pubs/stroke/#risk.
[43] Mayo Clinic. A1c test. 2013. Retrieved from http://www.mayoclinic.com/health/a1c-test/MY00142.
[44] Ibid.
[45] Ibid.
[46] Ibid.
[47] The Action to Control Cardiovascular Risk in Diabetes Study Group, Gerstein HC, Miller ME, et al. (2008). Effects of intensive glucose lowering in type 2 diabetes. *New England Journal of Medicine,* 358(24):2545-2559.
[48] ADVANCE Collaborative Group, Patel A, MacMahon S, et al. (2008). Intensive blood glucose control and vascular outcomes in patients with type 2 diabetes. *New England Journal of Medicine,* 358(24), 2560-2572.
[49] Stratton, I. M., Adler, A. I., Neil, H. A., et al. (2000). Association of glycaemia with macrovascular and microvascular complications of type 2 diabetes (UKPDS 35): prospective observational study. *British Medical Journal,* 321, 405-412.
[50] Chobanian, A. V., Bakris, G. L., Black, H. R., et al. (2003). Seventh report of the Joint National Committee on Prevention, Detection, Evaluation, and Treatment for High Blood Pressure. *Hypertension,* 42, 1206-1252.
[51] American Diabetes Association. (2002). Evidence-based nutrition principles and recommendations for the treatment and prevention of diabetes and related complications. *Diabetes Care*, 25:S50-S60.
[52] Estruch, R., Ros, E., Jordi, S., et al. (2013). Primary Prevention of Cardiovascular Disease with a Mediterranean Diet. *The New England Journal of Medicine,* 368, 1279-1290.
[53] Mayo Clinic. Diabetes diet: create your healthy eating plan. Retrieved from http://www.mayoclinic.com/health/diabetes-diet/DA00027.
[54] Story, M., Kaphingst, K.M., Robsinon-O'Brien, R., et al. (2008). Creating healthy food and eating environments: Policy and environmental approaches. *Annual Review of Public Health*. 29, 253-272.
[55] Ibid.
[56] Ibid.

[57] Larson N. I., Story M. T., & Nelson M. C. (2009). Neighborhood Environments: Disparities in Access to Healthy Foods in the U.S. *American Journal of Preventive Medicine,* 36(1), 74-81.

[58] Williams D. R. & Collins, C. (2001). Racial residential segregation: a fundamental cause of racial disparities in health. *Public Health Report,* 116, 404-416.

[59] United States Department of Agriculture. Food Deserts. Washington, DC: Agricultural Marketing Service, United States Department of Agriculture. Retrieved from http://apps.ams.usda.gov/fooddeserts/foodDeserts.aspx.

[60] Beaulac, J., Kristjansson, E., & Cummins, S. (2009). A systematic review of food deserts, 1966-2007. *Preventing Chronic Disease,* 6(3), 1-10.

[61] Ibid.

[62] Environmental and economic injustice fact sheet. Washington, DC: National Black Environmental Justice Network. Retrieved from http://www.ejrc.cau.edu/NBEJNEJFS.html.

[63] Kauffman, P. R., MacDonald, J., Lutz, S., et al. (1997). Do the poor pay more for food? Item selection and price differences affect low-income household food costs. Agricultural Economic Report-759. Washington, D.C.: Economic Research Service, United States Department of Agriculture.

[64] Drewnowski, A. & Specter, S. E. (2004). Poverty and obesity: the role of energy density and energy costs. *American Journal of Clinical Nutrition*, 79(1), 6-16.

[65] Rose, D., Bodor, J. N., Swalm, C. M., et al. (2009). Deserts in New Orleans? Illustrations of Urban Food Access and Implications for Policy. University of Michigan National Poverty Center/USDA Economic Research Service. Retrieved from http://www.npc.umich.edu/news/events/food-access/rose_et_al.pdf.

[66] Morris, P. M., Bellinger, M., & Haas, E. (1990). Higher prices, fewer choices: shopping for food in rural America. Washington, D.C.: Public Voice for Food and Health Policy. Retrieved from http://eric.ed.gov/?id=ED323079.

[67] Kauffman, P.R. (1999). Rural poor have less access to supermarkets, large grocery stores. *Rural Development Perspectives*, 13(3), 19-25.

[68] Morris, P. M., Neuhauser, L., and Campbell, C. (1992). Food security in rural America: a study of the availability and costs of food. *Journal of Nutrition Education*, 24(1), 52S-58S.

[69] Sharkey, J.R. (2009). Measuring Potential Access to Food Stores and Food-Service Places in Rural Areas in the U.S. *American Journal of Preventive Medicine,* 36(4S), S151-S155.

[70] Ibid.

[71] Larson, N. I., Story, M. T., & Nelson, M. C. (2009). Neighborhood Environments: Disparities in Access to Healthy Foods in the U.S. *American Journal of Preventive Medicine,* 36(1), 74-81.

[72] Powell, L., Slater, S., Mirtcheva, D., et al. (2007). Food store availability and neighborhood characteristics in the United States. *Preventive Medicine,* 44, 189-195.

[73] Horowitz, C.R., Colson, K.A., Hebert, P.L., et al. (2004). Barriers to buying healthy food for people with diabetes: evidence of environmental disparities. *American Journal of Public Health*, 94(9), 1549-1554.

[74] McKinnon, R.A., Reedy, J., Morrissette, M.A., et al. (2009). Measures of the food environment: A compilation of the literature, 1990-2007. *American Journal of Preventive Medicine*, 36(4S), S124-S133.
[75] Jilcott S.B., Wade S., McGuirt J.T., et al. (2011). The association between the food environment and weight status among eastern North Carolina youth. *Public Health Nutrition,* 14(9), 1610-1617.
[76] Ibid.
[77] Jilcott S.B., Wu Q., McGuirt J.T., et al. (2013). Associations between access to farmers' markets and supermarkets, shopping patterns, fruits and vegetable consumption and health indicators among women of reproductive age in eastern North Carolina, USA. *Public Health Nutrition,* 16(11), 1944-1952.
[78] Health Resources and Services Administration. How is rural defined? Washington, D.C.: Health Resources and Services Administration, U.S. Department of Health and Human Services. Retrieved from http://www.hrsa.gov/healthit/toolbox/RuralHealthITtoolbox/Introduction/defined.html.
[79] U.S. Census Bureau. (2013). Lumberton, North Carolina. Retrieved from http://quickfacts.census.gov/qfd/states/37/3739700.html.
[80] U.S. Census Bureau. (2013). Robeson County, North Carolina. Retrieved from http://quickfacts.census.gov/qfd/states/37/37155.html.
[81] Community Commons. (2014). Retrieved from http://maps.communitycommons.org/viewer/.
[82] County Health Rankings. (2013). North Carolina. University of Wisconsin Population Health Institute; Robert Wood Johnson Foundation. Retrieved from http://www.countyhealthrankings.org/app/north-carolina/2013/measure/factors/84/map.
[83] Robeson County 2011 Community Health Assessment. (2011). Lumberton, NC: Robeson County Health Department. Retrieved from http://publichealth.southernregionalahec.org/robeson/report.html.
[84] Aschengrau, A. & Seage, G.R. (2008). Essentials of Epidemiology in Public Health. Sudbury, MA: Jones and Bartlett Publishers, Inc.
[85] Texas A&M Geocoding Services. (2014). Retrieved from http://geoservices.tamu.edu/About/.
[86] Ammerman, A. (2012). Accessing Nutritious Food in Low-Income Neighborhoods. *North Carolina Medical Journal,* 73(5), 384-385.
[87] Ibid.
[88] Vajjhala, S. P. (2006). "Ground Truthing" Policy: Using Participatory Map-Making to Connect Citizens and Decision Makers. Resources for the Future. Retrieved from: http://www.rff.org/rff/Documents/RFF-Resources-162_GroundTruthing.pdf
[89] ReferenceUSA. (2014). Retrieved from http://referenceusa.com/Home/Home.
[90] Rose, D., Bodor, J. N., Swalm, C. M., et al. (2009). Deserts in New Orleans? Illustrations of Urban Food Access and Implications for Policy. University of Michigan National Poverty Center/USDA Economic Research Service. Retrieved from http://www.npc.umich.edu/news/events/food-access/rose_et_al.pdf.
[91] Jilcott S. B., Wade S., McGuirt J. T., et al. (2011). The association between the food environment and weight status among eastern North Carolina youth. *Public Health Nutrition,* 14(9), 1610-1617.

[92] Pebesma, E. J. & Bivand, R. S. (2005). Classes and methods for spatial data in R. *R News 5(2)*. Retrieved from http://cran.r-project.org/doc/Rnews/.
[93] Bivand, R. S., Edzer, J., & Pebesma, V. G. (2008). Applied spatial data analysis with R. Retrieved from http://www.asdar-book.org/
[94] Urbanek, S., Bibiko, H. J., & Iacus, S. M. The R Foundation for Statistical Computing. Retrieved from http://www.R-project.org.
[95] Laraia, B.A., Siega-Riz, A.M., Kaufman, J.S., et al. (2004). Proximity of supermarkets is positively associated with diet quality index for pregnancy. *Preventive Medicine,* 39(5), 869-875.
[96] Jeffrey, R.W., Baxter, J., McGuire, M., et al. (2006). Are fast food restaurants an environmental risk factor for obesity? *International Journal of Behavioral Nutrition and Physical Activity,* 3(35).
[97] Sharkey, J.R., Johnson, C.M., Dean, W.R., et al. (2011). Association between proximity to and coverage of traditional fast-food restaurants and non- traditional fast-food outlets and fast-food consumption among rural adults. *International Journal of Health Geographics,* 10(37), 1-11.
[98] Ibid.
[99] Ver Ploeg, M., Breneman, V., Farrigan, T., et al. (2012). Access to Affordable and Nutritious Food: Measuring and Understanding Food Deserts and Their Consequences. Chapter 4. pg. 1-59. U.S. Department of Agriculture.
[100] Zenk, S. N., Schulz, A. J., Hollis-Neely, T., et al. (2005). Fruit and Vegetable Intake in African Americans: Income and Store Characteristics. *American Journal of Preventive Medicine*, 29(1), 1-9.
[101] Schulz, A. J., Kannan, S., Dvonch, J. T., et al. (2005). Social and Physical Environments and Disparities in Risk for Cardiovascular Disease: The Healthy Environments Partnership Conceptual Model *Environmental Health Perspectives*, 113(12), 1817-1825.
[102] Thornton, L. E., Bentley, R. J., & Kavanagh, A. M. Fast food purchasing and access to fast food restaurants: a multilevel analysis of VicLANEs. *International Journal of Behavioral Nutrition and Physical Activity,* 6(28).
[103] Subramanian, S. V., Glymour, M., & Kawachi, I. (2007). Identifying causal ecological effects on health: a methodological assessment. *Macrosocial Determinants of Population Health.* Edited by Galea S. New York: Springer, 301-331.
[104] Fleischer, N. L. & Diez Roux, A. V. (2008). Using directed acyclic graphs to guide analyses of neighbourhood health effects: an introduction. *Journal of Epidemiol Community Health*, 62(9), 842-846.
[105] Rorive, M., Letiexhe, M. R., Scheen, A. J., et al. (2005). Obesity and type 2 diabetes. *Rev Med Liege,* 60(5-6), 374-382.
[106] American Diabetes Association. Modifiable Risk Factors. Retrieved from: http://professional.diabetes.org/resourcesforprofessionals.aspx?cid=60382#Hypertension.
[107] Ibid.
[108] O'Connell, J., Yi, R., Wilson, C., et al. (2010). Racial Disparities in Health Status: A comparison of the morbidity among Americans Indian and U.S. adults with diabetes. *Diabetes Care,* 33(7), 1463-1470.

[109] Trivedi, T., Liu, J., Probst, J. C., et al. The Metabolic Syndrome: Are Rural Residents at Increased Risk? *Journal of Rural Health,* 29(2), 188-197.
[110] Eldeirawi, K., & Lipton, R. B. (2003). Predictors of Hemoglobin A1c in a National Sample of Nondiabetic Children. *American Journal of Epidemiology,* 157(7), 624-632.
[111] Hosmer, D. W., Lemeshow, S., & Sturdivan, R. X. (2013). Applied Logistic Regression. 3rd Edition.
[112] Fox, J. & Weisberg, S. An R Companion to Applied Regression. 2nd Edition.
[113] Ibid.
[114] Ibid.
[115] U.S. Census Bureau. (2014). Geographic Terms and Concepts – Block Groups. U.S. Census Bureau. Retrieved from: http://www.census.gov/geo/reference/gtc/gtc_bg.html.
[116] Sharkey, J.R. & Horel, S. (2008). Neighborhood Socioeconomic Deprivation and Minority Composition Are Associated with Better Potential Spatial Access to the Ground-Truthed Food Environment in a Large Rural Area. *Journal of Nutrition,* 138(3), 620-627.
[117] R Core Team. (2012). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/.
[118] Pagano, M. & Gauvreau, K. (2000). Principles of Biostatistics. Pacific Grove, CA: Duxbury.
[119] Higgins, T., Cembrowski, G., Tran, D., et al. (2009). Influence of Variables on Hemoglobin A1c Values and Nonheterogeneity of Hemoglobin A1c Reference Ranges. *Journal of Diabetes Science and Technology,* 3(4), 644-648.
[120] Health Resources and Service Administration. Diabetes HbA1c (Poor Control). Retrieved from: http://www.hrsa.gov/quality/toolbox/measures/diabetes/
[121] National Heart, Lung, and Blood Institute. Calculate Your Body Mass Index. Retrieved from: https://www.nhlbi.nih.gov/guidelines/obesity/BMI/bmicalc.htm
[122] County Subdivision Outline Map Legend and County Location Index. U.S. Census Bureau, Census 2000. Retrieved from: http://www2.census.gov/geo/maps/general_ref/cousub_outline/cen2k_pgsz/nc_cosub.pdf
[123] Multicollinearity. Retrieved from: http://www.chsbs.cmich.edu/fattah/courses/empirical/multicollinearity.html.
[124] Britton, K. A., Pradhan, A. D., & Sesso, H. D. Hemoglobin A1c, body mass index, and the risk of hypertension in women. (2011). American Journal of Hypertension, 24(3), 328-334.
[125] Huang Z., Willett, W. C., Manson, J.E., et al. (1998). Body weight, weight change, and risk for hypertension in women. *Annals of Internal Medicine,* 128(2), 81-8.
[126] Gelber, R. P., Gaziano, J. M., Manson, J. (2007). A prospective study of body mass index and the risk of developing hypertension in men. *American Journal of Hypertension,* 20(4), 370-7.
[127] Britton, K. A., Pradhan, A. D., & Sesso, H. D. Hemoglobin A1c, body mass index, and the risk of hypertension in women. (2011). American Journal of Hypertension, 24(3), 328-334.

[128] Singer, D.E., Nathan, D.M., Anderson, K.M., et al. (1992). Association of HbA1c with prevalent cardiovascular disease in the original cohort of the Framingham Heart Study. *Diabetes,* 41(2), 202-8.
[129] Britton, K. A., Pradhan, A. D., & Sesso, H. D. Hemoglobin A1c, body mass index, and the risk of hypertension in women. (2011). American Journal of Hypertension, 24(3), 328-334.
[130] Eldeirawi, K., & Lipton, R. B. (2003). Predictors of Hemoglobin A1c in a National Sample of Nondiabetic Children. *American Journal of Epidemiology,* 157(7), 624-632.
[131] Okauchi, Y., Iwahashi, H., Okita, K., et al. (2013). Weight reduction is associated with improvement of glycemic control in Japanese men, whose hemoglobin A1C is 5.6–6.4%, with visceral fat accumulation, but not without visceral fat accumulation. *Journal of Diabetes Investigation,* 4(5), 454-459.
[132] Franz, M. J. (2007). The Dilemma of Weight Loss in Diabetes. *Diabetes Spectrum,* 20(3), 133-136.
[133] Sharkey, J. R., Horel, S., & Dean, W. R. (2010). Neighborhood deprivation, vehicle ownership, and potential spatial access to a variety of fruits and vegetables in a large rural area in Texas. *International Journal of Health Geographics,* 9(26), 1-27.
[134] Sharkey, J.R., Johnson, C.M., Dean, W.R., et al. (2011). Association between proximity to and coverage of traditional fast-food restaurants and non-traditional fast-food outlets and fast-food consumption among rural adults. *International Journal of Health Geographics,* 10(37).
[135] Ibid.
[136] Horowitz, C.R., Colson, K.A., Hebert, P.L., et al. (2004). Barriers to buying healthy foods for people with diabetes: evidence of environmental disparities. *American Journal of Public Health,* 94(9), 1549-1554.
[137] Ayala, G. X., Baquero, B., Laraia, B. A., et al. (2013). Efficacy of a store-based environmental change intervention compared with a delayed treatment control condition on store customers' intake of fruits and vegetables. *Public Health Nutrition,* 16(11), 1953-1960.
[138] New York City Department of Health and Mental Hygiene.Healthy Bodegas Initiative: A Program of the Department of Health and Mental Hygiene. Retrieved from: http://www.nyc.gov/html/ceo/downloads/pdf/BH_PRR.pdf.
[139] The Food Trust, the Philadelphia Healthy Corner Store Network, and Get Healthy Philly. Philadelphia Healthy Corner Store Initiative, 2010-2012. Retrieved from: http://thefoodtrust.org/uploads/media_items/hcsi-y2report-final.original.pdf.
[140] Rothman, R. L., Mulvaney, S., Elasy, T. A., et al. (2008). Self-management behaviors, racial disparities, glycemic control among adolescents with type 2 diabetes. *Pediatrics,* 121(4), 912-919.
[141] Jilcott, S. B., Wade, S., Mcguirt, J. T., et al. (2011). The association between the food environment and weight status among eastern North Carolina youth. *Public Health Nutrition,* 14, 1610–1617.
[142] Davis, B. & Carpenter, C. (2009). Proximity of fast food restaurants to schools and adolescent obesity. *American Journal of Public Health,* 99(3), 505-510.

[143] Wang, M., Cubbin, C., Ahn, D., et al. (2007). Changes in neighborhood food store environment, food behaviour and body mass index, 1981–1990. *Public Health Nutrition*, 11, 963–970.
[144] Li, F., Harmer, P., Cardinal, B., et al. (2008). Built environment, adiposity, and physical activity in adults aged 50–75. *American Journal of Preventive Medicine*, 35, 38–46.
[145] Fleischhacker, S. E., Evenson, K. R., Rodriguez, D. A., et al. 2011. A systematic review of fast food access studies. *Obesity Reviews,* 12, 460-471.
[146] Gustafson, A., Hankins, S., and Jilcott, S. (2011). Measures of the consumer food store environment: a systematic review of the evidence 2000-2011. *Journal of Community Health,* 37(4), 897-911.
[147] Giskes, K., Kamphuis, C. B., Van Lenthe, F. J., et al. (2007). A systematic review of associations between environmental factors, energy and fat intakes among adults: Is there evidence for environments that encourage obesogenic dietary intakes? *Public Health Nutrition,* 10, 1005–1017.
[148] Morland, K., Diez Roux, A. V, & Wing, S. Supermarkets, Other Food Stores, and Obesity: The Atherosclerosis Risk in Communities Study. *American Journal of Preventive Medicine,* 30(4), 333-339.
[149] Millstein, R. A., Yeh, H., & Gary, T. L. (2009). Food Availability, Neighborhood Socioeconomic Status, and Dietary Patterns Among Blacks With Type 2 Diabetes Mellitus. *The MedScape Journal of Medicine,* 11(1), 15.
[150] Morland, K., Diez Roux, A. V, & Wing, S. Supermarkets, Other Food Stores, and Obesity: The Atherosclerosis Risk in Communities Study. *American Journal of Preventive Medicine,* 30(4), 333-339.
[151] Inagami, S., Cohen, D. A., Finch, B. K., et al. (2006). You are where you shop: Grocery store locations, weight, and neighborhoods. *American Journal of Preventive Medicine,* 31(1), 10-17.
[152] Eakin, E. G., Bull, S. S., Riley, K. M, et al. Resources for Health: A Primary-Care-Based Diet and Physical Activity: Intervention Targeting Urban Latinos With Multiple Chronic Conditions. *Health Psychology,* 26(4), 392-400.
[153] Staten, L. K., Gregory-Mercado, K. Y., Ranger-Moore, J., et al. (2004). Provider Counseling, Health Education, and Community Health Workers: The Arizona WISEWOMAN Project. *Journal of Women's Health,* 13(5), 547-556.
[154] Sturm, R. & Cohen, D. A. Zoning For Health? The Year-Old Ban On New Fast-Food Restaurants In South LA. *Health Affairs,* 28(6), w1088-w1097.
[155] Dumanovsky, T., Huang, C. Y., & Silver, L.D. (2011). Changes in energy content of lunchtime purchases from fast food restaurants after introductionof calorie labeling: cross sectional customer surveys. *British Medical Journal,* 343, d4464.
[156] Mayo, M. L., Jilcott Pitts, S. B., & Chriqui, J. F. (2013). Associations between county and municipality zoning ordinances and access to fruit and vegetable outlets in rural North Carolina, 2012. *Preventing Chronic Disease,* 10, E203.
[157] Ibid.
[158] Ibid.
[159] Chriqui, J.F., Thrun, E., Rimkus, L., et al. (2012). Zoning for healthy food access varies by community income — a BTG research brief. Chicago (IL): Bridging the Gap

Program, Health Policy Center, Institute for Health Research and Policy, University of Illinois at Chicago.

[160] Ibid.

[161] Mayo, M. L., Jilcott Pitts, S. B., & Chriqui, J. F. (2013). Associations between county and municipality zoning ordinances and access to fruit and vegetable outlets in rural North Carolina, 2012. *Preventing Chronic Disease,* 10, E203.

[162] Chriqui, J.F., Thrun, E., Rimkus, L., et al. (2012). Zoning for healthy food access varies by community income — a BTG research brief. Chicago (IL): Bridging the Gap Program, Health Policy Center, Institute for Health Research and Policy, University of Illinois at Chicago.

[163] Farmer, A. (2012). Use of HbA1c in diagnosis of diabetes. *British Medical Journal*. 345.

[164] Higgins, T., Cembrowski, G., Tran, D., et al. (2009). Influence of Variables on Hemoglobin A1c Values and Nonheterogeneity of Hemoglobin A1c Reference Ranges. *Journal of Diabetes Science and Technology.* 3(4), 644-648.

[165] Mayo Clinic. (2014). A1c test. Retrieved from http://www.mayoclinic.com/health/a1c-test/MY00142/DSECTION=results.

[166] Blanchard, T. C. & Lyson, T. A. (2005). Retail concentration, food deserts, and food disadvantaged communities in rural America. Southern Rural Development Center. Available from: http://srdc.msstate.edu/ridge/projects/recipients/02_blanchard_final.pdf.

[167] Sharkey, J. R., Johnson, C. M., Dean, W. R., et al. (2011). Association between proximity to and coverage of traditional fast-food restaurants and non-traditional fast-food outlets and fast-food consumption among rural adults. *International Journal of Health Geographics,* 10, 37.

[168] Fleischhacker, S. E., Evenson, K. R., Rodriguez, D. A., et al. (2011). A systematic review of fast food access studies. *Obesity Reviews,* 12, 460-471.

[169] Jilcott, S. B., Wade, S., Mcguirt, J. T., et al. (2011). The association between the food environment and weight status among eastern North Carolina youth. *Public Health Nutrition,* 14, 1610–1617.

[170] Sharkey, J. R., Johnson, C. M., Dean, W. R., & Horel, S. A. (2011). Association between proximity to and coverage of traditional fast-food restaurants and non-traditional fast-food outlets and fast-food consumption among rural adults. *International Journal of Health Geographics,* 10(37).

[171] Krishnan, S., Cozier, Y. C., Rosenberg, L., et al. (2009). Socioeconomic status and incidence of type 2 diabetes: results from the Black Women's Health Study. *American Journal of Epidemiology,* 171(5), 564-570.

[172] Beaulac, J., Kristjansson, E., & Cummins, S. (2009). A systematic review of food deserts, 1966-2007. *Preventing Chronic Disease,* 6(3), 1-10.

[173] Ver Ploeg, M., Breneman, V., Farrigan, T., et al. (2012). Access to Affordable and Nutritious Food: Measuring and Understanding Food Deserts and Their Consequences. Chapter 4. pg. 1-59. U.S. Department of Agriculture.

[174] The Prevalence of Meeting A1C, Blood Pressure, and LDL Goals Among PeopleWith Diabetes, 1988–2010. Casagrande, Rust, Fradkin, etc.